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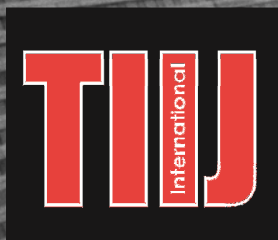
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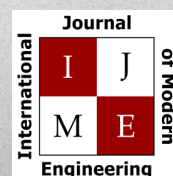
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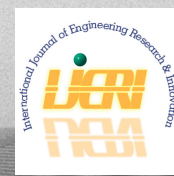
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# PERFORMANCE EVALUATION, ANALYSIS, AND UTILIZATION IMPROVEMENT OF A LABEL PRINTER WORKSTATION USING DISCRETE-EVENT SIMULATION

Ankhubayar Baasandorj, Purdue University Northwest; Ali Alavizadeh, Purdue University Northwest

## Abstract

In this paper, the authors discuss a feasibility study of automating a label printer workstation through discrete-event simulation implemented in Simio. The initial study and discussion with the line supervisor indicated some inefficiency in their printing workstation in terms of utilization. In particular, the study focused on determining whether or not robotic arms could improve printer utilization (there were five printers with two operators for the entire workstation). The analysis of the results showed that, with the automation of the loading and unloading operations by robots with a single operator, the production capacity of the workstation could be increased slightly. This would allow the company to process more plates as well as a possible cost reduction in production, which could be a beneficial decision for the company.

## Introduction

Discrete event simulation (DES) is a powerful tool that can be used by a company's management, as it provides the spot-on knowledge essential to the company's resource distribution analysis and assessment of its production process capabilities. Through DES, a variety of real-world production systems can be studied. Using the simulation modeled, the process design can be tested against different scenarios and arrangements in a production line without involving actual risks. As the simulated model can be tested for any possible/hypothetical scenario, informed decisions can be made regarding investment in a production plant, its expansion or reforms, balancing of production lines, etc. (Yesilgul & Nasser, 2013). The printing workstation studied was part of a production line in a mid-west manufacturing company. Figure 1 shows the workstation that printed labels for various indicators found in commercial pressure gauges. The line supervisor and the plant engineer at the company initially stated that their preliminary studies showed that the workstation output could be further improved through automation (i.e., using robotic arms). Yet, they were not sure if such automation would be useful. The focus of this current study was on utilization improvement of workstations.

## Statement of the Problem, Goals, and Objectives

The underutilized printing workstation of the company needed to be optimized in terms of machine utilization. The

goal of the project was to study the workstation using discrete-event modeling and simulation in order to evaluate various optimization scenarios.



Figure 1. The printed panel behind the pointer of a typical gage.

## Literature Review

Simulation modeling is an effective tool in the area of operations research that helps approximate real-world behaviors and studies the resilience of a system against a range of test scenarios. Additionally, creating a simulation produces a high-level understanding of the system for the modeler (Maidstone, 2012). There are mainly three approaches to simulation: DES, system dynamics (SD), and agent-based simulations (ABS). DES models a process as a sequence of events. The entities move between states as time passes. Viewed as a network of servers and queues, DES helps determine the addition of new servers, entities, or restructuring of the network (Maidstone, 2012). SD models focus on network flow rather than the entities' behaviors. The model forms a network of stocks, flows, and delays and evaluates them against some criterion. System behaviors are studied through the types of flows. Lastly, ABS is based upon autonomous agents that are fed with rules and a goal. The model simulates how an agent would interact with its environment and other agents. The choice of the approach may depend on the type of problem being solved.



The three models can also be used alongside one another to model a system. DES is a bottom-up modeling approach that is used for systems that have queues, while SD is ideally used for systems that have natural flows (e.g., water pipes or when a simple view of a very large complex system is required). SD uses a top-down modeling approach, while ABS and DES are bottom-up approaches. Unlike SD and ABS, DES is a stochastic model and gives different results on different runs, while simultaneously handling randomness. The entities are passive in DES; in ABS, unlike DES, the entities are active. ABS modeling takes longer to model and run compared with DES and SD (Maidstone, 2012).

Simulations have been extensively used by the manufacturing sector to evaluate the current state, investigate improvement areas, and estimate the impact of certain scenarios. For highly variable and complex systems, the use of simulations becomes inevitable. DES is an important tool for providing solutions to production sector problems, such as workers assignment, allocating resource, production line designing, and workload balancing (Salama, Abdelhalim & Eltawil, 2017). The main goal of using DES for production lines is cost and cycle time reduction, bottleneck elimination, increasing productivity, and resource utilization (Prajapat & Tiwari, 2017).

The DES approach helps design optimized production processes (Zupan & Herakovic, 2015). The simulations can be designed for existing or non-existing production lines. Therefore, the approach can be used effectively for both small and large, real or imaginary enterprises. Due to its what-if conditional logic, the system behavior can be studied using hypothetical test scenarios, which can be visualized by merely providing the different input parameters. Studying the behavior of design can help avoid unnecessary costs, as the system can accurately predict system behavior within a specific scenario. DES was used to prove how incorporating robots into a production line can increase its productivity, where modeled three types of production lines were modeled: an ideal production line, a production line with human workers, and one where human workers were replaced with robots (Kampa, Gołda & Paprocka, 2017). The ideal production line highlighted the maximum achievable production rate. The model had constraints and noise added to it as availability control, buffers, and time schedule. Factors typical to the manufacturing sector were also added with constant and varying values, machine cycle time, a stochastic value for operator time for a worker, and constant speed for loading/unloading time for the robot.

DES was also employed to optimize the layout of two individual production lines of an automobile company that produced and stored the products in the production area (Kurkin & Šimon, 2011). The objective was to reduce the special arrangement of the two lines and optimize the layout with regards to planned production. The space saved by the merger of the two lines was to start another production line in the same production hall. The two production lines were

simulated and five layout variants were modeled. The variant that scored the highest against evaluation criterion—such as quality, the distance between operations, costs, material flows, continuity, transport, number of operators, noise level, etc.—were selected. The merged production lines worked in shifts. The case study showed how DES helped come up with a decision based on realistic data. Simio was used to create a DES model for an assembly line of die carton boxes. Two models were made, one for the existing assembly line and another for the new system with lean principles implemented. The simulation experiments estimated the requirement of resources and performance, thus quantifying the benefits of implementing lean principles (Ares, Peláez, Ferreira, Prieto & Chao, 2012).

DES, nevertheless, holds certain strengths and weaknesses. The strengths include its ability to allow studying and experimenting on complex systems, feasibility testing of a phenomenon, while the weaknesses could be the requirement of training to model, and the simulation being subjected to randomness (Sharma, 2015). An important factor that determines the successful application of DES for a production site is the quality of data that is collected to create the simulation (Bokrantz, Skoogh, Länkull, Hanna, & Perera, 2018). Limited accessibility, missing details on minor nuisances, irrelevant data, etc. are a few aspects that may cause the simulation to fail, taking into account the actual process prevalent on a production line.

## The Workstation

There were two operators that worked eight hours a day and on five printers. Out of these, four had the same specifications, while the remaining larger printer was different. Operator 2 handled one of the four similar printers as well as the unique larger printer. Operator 1 handled the remaining three similar printers. Figure 2 shows the label printer workstation.



Figure 2. Label printer workstation.

Figure 3 shows that there were five different plates and each plate could be placed on seven types of jigs. The printer capacity and compatibility with the plates and jigs varied. The combination was selected according to the label that needed to be printed.



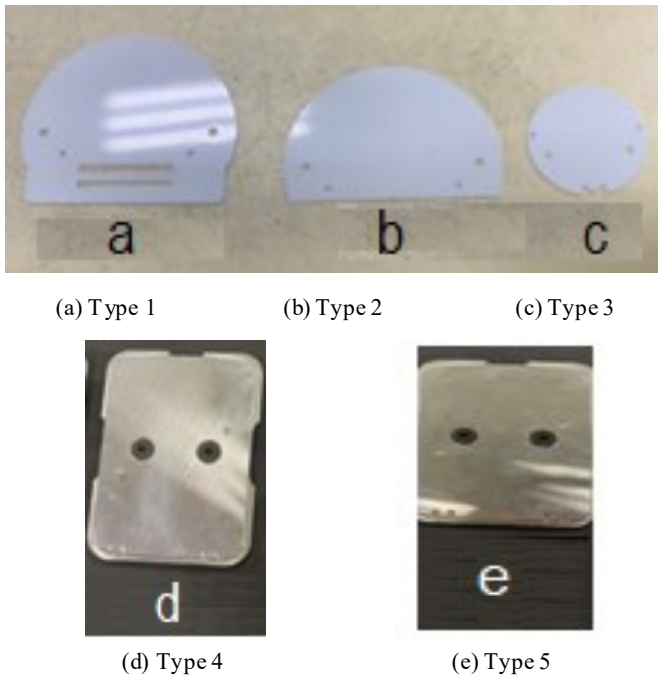


Figure 3. Plate types.

The operators had a working procedure that catered to the orders put forward. The orders that agreed with the active printer settings were printed first. While the printer was working, the remaining plates were stacked onto a rack of 42 pieces. The operators left when their time was up. Printers turned off automatically once the active job was complete. The plates were placed onto jigs. Figure 4 shows that there were seven interchangeable jigs. Each jig could hold a certain type of plate.

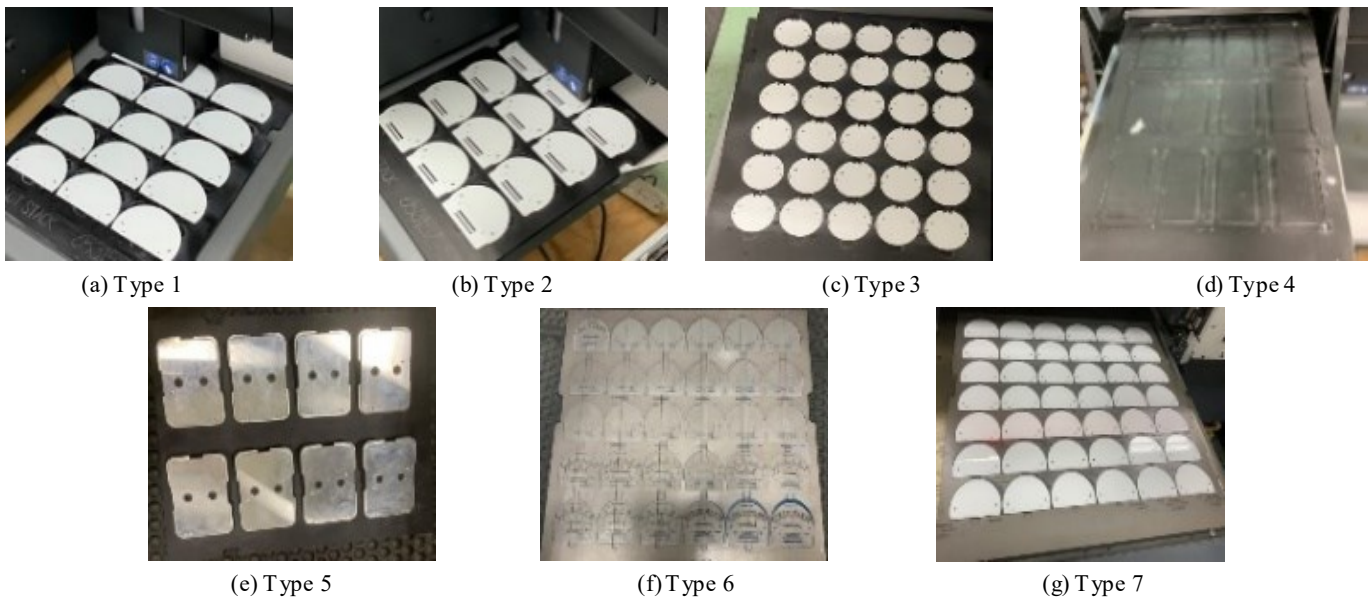


Figure 4. Seven jigs for different plate types.

Tables 1-3 detail the capacities of the different printers and the jigs with which they were compatible. Tables 4 and 5 detail the plate types for each jig.

Table 1. Plate types for respective printers.

	Plate Type 1	Plate Type 2	Plate Type 3	Plate Type 4	Plate Type 5
Printer 1	+	+	N/A	N/A	N/A
Printer 2	+	+	+	N/A	N/A
Printer 3	+	+	+	+	+
Printer 4	+	+	+	+	+
Printer 5	+	+	+	+	+

Note: +: a jig type/plate type was compatible with respective printer type. N/A: a jig type/plate type was not compatible with respective printer type.

Table 2. Jig compatibility with each printer.

	Printer 1	Printer 2	Printer 3	Printer 4	Printer 5
Jig 1	N/A	+	+	+	+
Jig 2	N/A	+	+	+	+
Jig 3	N/A	+	+	+	+
Jig 4	N/A	N/A	+	+	+
Jig 5	N/A	N/A	+	+	+
Jig 6	+	N/A	N/A	N/A	N/A
Jig 7	+	N/A	N/A	N/A	N/A

Table 3. Plate types were compatible with each jig type and its respective quantity.

	Plate Type 1	Plate Type 2	Plate Type 3	Plate Type 4	Plate Type 5
Jig 1	12pcs	N/A	N/A	N/A	N/A
Jig 2	N/A	15pcs	N/A	N/A	N/A
Jig 3	N/A	N/A	30pcs	N/A	N/A
Jig 4	N/A	N/A	N/A	12pcs	N/A
Jig 5	N/A	N/A	N/A	N/A	8pcs
Jig 6	30pcs	N/A	N/A	N/A	N/A
Jig 7	N/A	42pcs	N/A	N/A	N/A

Table 4. The total jig quantity for each plate type with which it was compatible.

	Plate Type 1	Plate Type 2	Plate Type 3	Plate Type 4	Plate Type 5
Jig Quantity	6pcs	4pcs	3pcs	1pc	2pcs

Table 5. The total jig quantity for each jig type.

Jig Type 1	Jig Type 2	Jig Type 3	Jig Type 4	Jig Type 5	Jig Type 6	Jig Type 7
5pcs	3pcs	3pcs	1pcs	2pcs	1pcs	1pc

## The Production Routine

Following is a summary of the daily routine of the workstation.

For the printer:

- The printer's startup at the beginning of the day.
- The daily production schedule is assigned to each printer.
- The printers print the plates that are loaded into the machine on the jig by the operator once they are ready to process.

For the operators:

- They start the printers.
- Prepare or wait until the printers are ready.
- Open the lid of the printers.
- If required, perform changeover.
- Place the plates on the jig inside the printer one by one.
- Clean the plates with alcohol.
- Close the lid and start the printer.

When the printing is finished, the operators

- Take out the plates one by one.
- Check their quality.
- When 42 pieces of the same plate type is reached, they are made into bundle and are put on a rack to exit the workstation.

## Modeling and Simulation

The data collected for this project were very limited, due to the limited timeframe and deficiency of data provided by the company. The data were collected for the following operations: changeover times, plate loading and unloading times, printer processing times, cleaning time, and bundling process. The processing times of the printers depended primarily on the jig loaded into the printer. The data for the processing times of printers were collected using the log files of each printer. The log files of the printers showed fixed processing times for each plate type in each printer when jigs were fully loaded. These data were imported into Simio using the data tab in unit of hours.

Figure 5 shows the model that was built using Simio. The model was merely based on the printing workstation, where two operators placed the blank plates into the appropriate jigs, as shown on the left side of the figure, and then loaded the jigs into the available printers, as shown in the center of the figure. Eventually, once the plates were printed, they inspected them and, depending on whether the quality of the printed plates satisfactory, the operators would move them to their corresponding racks (i.e., satisfactory or unsatisfactory), as shown on the right side of the figure. The simulation ran 100 replications over a period of one month. The model was verified and validated by comparing the model with the actual workstation steps and procedures, as well as the historical production data that the company had provided.

## Discussion

The analysis showed that the label printer workstation was able to meet the production of the orders on time. However, Table 6 shows that utilization of printers still needed to be improved.

Table 6. Utilization of the printers.

Printer	Utilization rate %	Time starved % (free capacity)
Printer 1	47.14	17.96
Printer 2	26.97	24.81
Printer 3	53.47	15.8
Printer 4	23.77	25.9
Printer 5	22.04	26.49

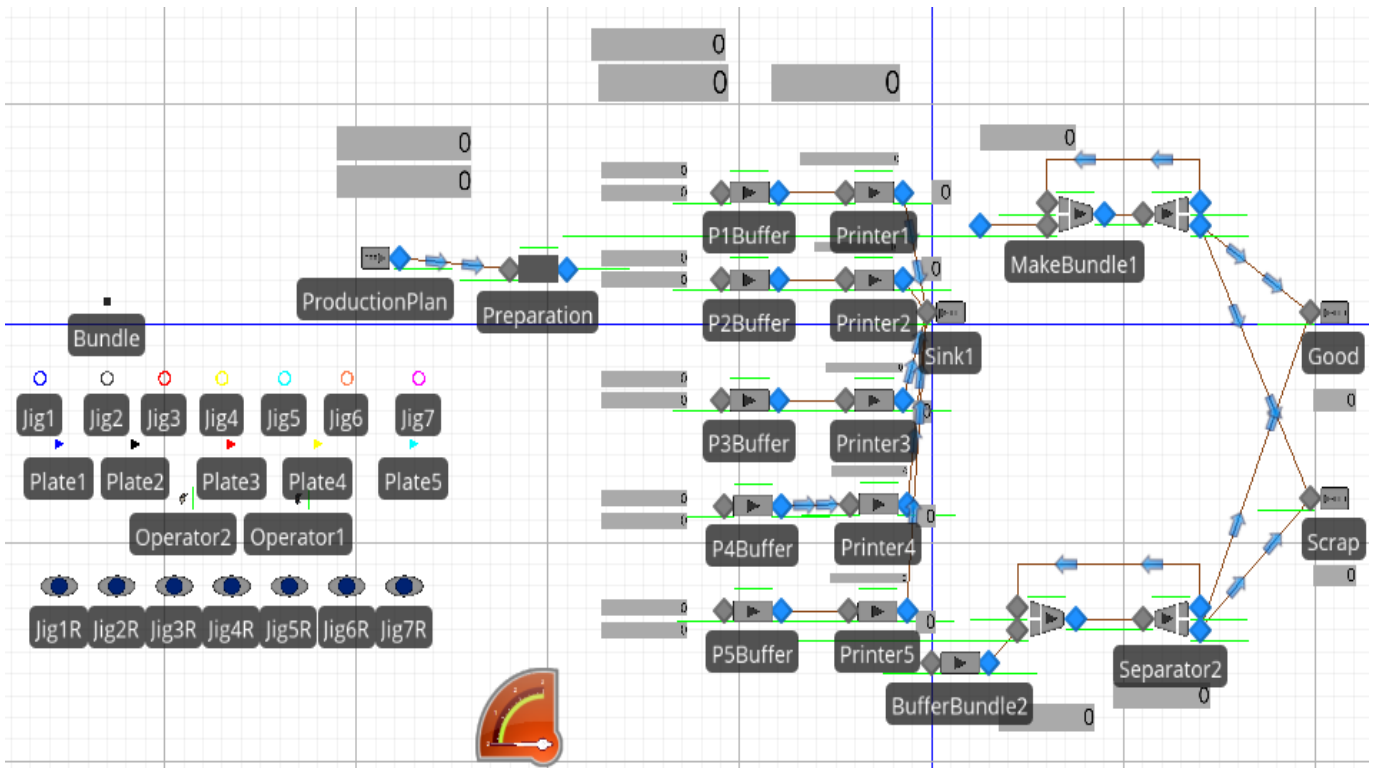


Figure 5. The Simio model of the workstation.

The workstation was able to handle more plates; however, the printers “starved” in the sense that one needed to feed plates more often. Hence, a scenario was examined where a robot next to each printer completed the loading and unloading tasks. Therefore, in the computer model, a hypothetical robotic arm was assigned to each printer to help the operators with loading and unloading. According to the line supervisor and engineer, it took a longer time for operator 2 to perform similar tasks (i.e., start the printer, prepare, etc.) compared with operator 1. Collected data supported these observations, since the data for operator 1 approximately followed a triangular distribution (10, 15, 20), while for operator 2 it was still triangular but with (15, 25, 35) for the majority of various jigs (units are all in minutes). However, to examine the model with hypothetical robotic arms, it was assumed that the changeover time (i.e., the time to take out the printed plates and to load the blank ones) would be identical for both operators.

The simulation was repeated with the same running parameters (100 replicates, one month). Table 7 shows the utilization for this scenario. As shown in the table, the utilization rates of each printer slightly increased or remained unchanged. One reason is that the simulation with robots was performed using the same daily operation schedule that was set for five printers without any robotic help. This indicated that the workstation could handle more parts.

Table 7. Comparison of printer utilization.

Printer	Initial Utilization rate %	Alternative Scenario Utilization rate %
Printer 1	47.14	50.15
Printer 2	26.97	27.9
Printer 3	53.47	57.83
Printer 4	23.77	25.7
Printer 5	22.04	23.72

Table 8 shows the utilization for each operator. As seen here, the utilization rate of the operators was lower after robots were added (6.73% for operator 1 and 2.25% for operator 2). It seemed that only one operator would be able to handle the entire workstation with help of robots.

Table 8. Comparison of operator utilization.

Operator	The current %	After robots are added %
Operator 1	19.45	6.73
Operator 2	8.11	2.25

This possibility was examined by running the simulation with only one operator and five robots. Table 9 shows the printer utilization for this case. Again, one can see that there was a slight improvement in printer utilization. Another simulation experiment was performed to examine the impact of a ramped-up production (i.e., doubling the order for the workstation) in order to evaluate the optimal output quantity and the utilization of operators and printers. Tables 10 and 11 shows these results.

Table 9. Comparison of printer utilization with one operator and five robots.

Printer	Initial Utilization rate %	Single operator with robots is added %
Printer 1	47.14	50.07
Printer 2	26.97	27.92
Printer 3	53.47	58.7
Printer 4	23.77	25.96
Printer 5	22.04	23.98

Table 10. Results comparison for the utilization rates between each scenario after daily schedules were doubled.

Printer	Initial Utilization rate %	Daily schedule has been doubled
Printer 1	47.14	97.29
Printer 2	26.97	64.24
Printer 3	53.47	99.99
Printer 4	23.77	55.83
Printer 5	22.04	52.38

Table 11. Results comparison for the utilization rates between each operator after daily schedules were doubled.

Operator	The current %	After schedule being doubled %
Operator 1	19.45	45.09
Operator 2	8.11	15.78

As can be seen, the utilization of each printer and the operators would considerably increase. However, as mentioned previously, the daily operation schedule for the printing workstation allowed for certain numbers of printed plates of each type. Therefore, in order to achieve this potential increase, one should modify the daily schedule, provided that this modification does not affect the overall production output negatively (i.e., more plates are being printed for which there is no order from a customer).

## Conclusions

The aim of this study was to examine the impact of incorporating automation, such as using robotic arms, on the printing workstation's utilization. The simulation of the current system showed relatively low utilization of the operators and printers. A new model was built and simulated in which a hypothetical robotic arm was added to each printer to help with loading and unloading and with only one operator running all five printers. The analysis showed that the production capacity of the workstation could be increased. This would allow the workstation to print more plates, as well as provide a possible cost reduction in production for the company. Yet, one should consider the acquisition cost of the robots, as well as training and maintenance cost for the operator(s). Although these considerations were not within the scope of this study, a comparison of the results shown in Tables 7 and 9 suggests that an increase in workstation utilization does not seem to be significant enough to justify acquisition of a robotic system. Such decisions require more in-depth analysis to avoid any unprecedented outcome.

Modeling and simulation is a powerful tool for running and comparing several scenarios in order to examine the impact of changes (e.g., automation, workforce balancing, software/hardware modification, etc.) on the system's output and utilization without implementing actual changes. The key element in using the results of any simulation experiment is to first verify and validate the model and its results. Verification and validation should be performed on the current system model so that one can compare the simulated results with actual ones produced on the floor. Once verified and validated, the model can be used to run several scenarios involving changes in workstations, queuing system, etc.

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- include numerical methods and applied modeling and simulation. Dr. Alavizadeh may be reached at [aalaviza@pnw.edu](mailto:aalaviza@pnw.edu)

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# VIRTUAL COMMISSIONING OF MANUFACTURING AUTOMATION AND ROBOTICS SYSTEMS USING A 3D ENVIRONMENT

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## Abstract

To develop a manufacturing system, several phases are often executed sequentially: facility design, mechanical engineering, electrical engineering, and automation engineering (programming of robots, PLCs, and HMI). Modeling physical facilities more accurately results in a higher expected benefit. Therefore, genuine production environments need to be attentively simulated. Based on model libraries and standardized recipes for the design of component models from CAD data, the author illustrates in this paper new concepts for the systematic and simplified design of manufacturing system models for virtual commissioning (VC) and how they could become viable for control systems engineers and commissioning engineers to lead a VC for production systems according to planning information.

VC does not require a high position of skill in model construction and simulation. This simplicity will entail that CAE and simulation tools extend the suitable performance, particularly high-level simulation model building from the CAE planning database. In addition to the enhanced tool situation, the object-oriented information base includes simulation models of a fabricating system. Figure 1 shows how, by means of digital models, computer-aided planning and design, computer-aided engineering, associated software tools and, with the aid of integrated data management, the Digital Factory would permit integrated planning, simulation, and validation of manufacturing processes and systems.

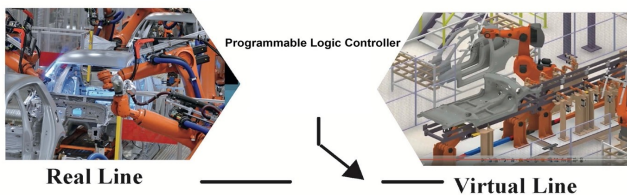


Figure 1. Digital Factory simulating the manufacturing process.

## Introduction

Manufacturing systems consist of various components: storage, magazines, conveyors, handling and transportation systems, machining and assembling tools, robots, control and HMI systems, as well as many standard and purpose-built parts or sub-systems (Hoffmann, Schumann, Maksoud & Premier, 2010).

The commissioning process can be separated into four categories. First, Real Commissioning uses a real facility with a real controller. Second, Reality-in-the-Loop Commissioning uses a real facility with a virtual controller. Third, Constructive Commissioning uses a virtual facility with a virtual controller. Finally, Virtual Commissioning uses a virtual facility with a real controller, integrating real and digital components into a single system (Lee, & Park, 2014). Because they are simple and cost effective, programmable logic controllers (PLCs) are most widely used in industry as controllers for production systems. Figure 2 shows how these PLCs are connected to software via an open platform communications (OPC) protocol.

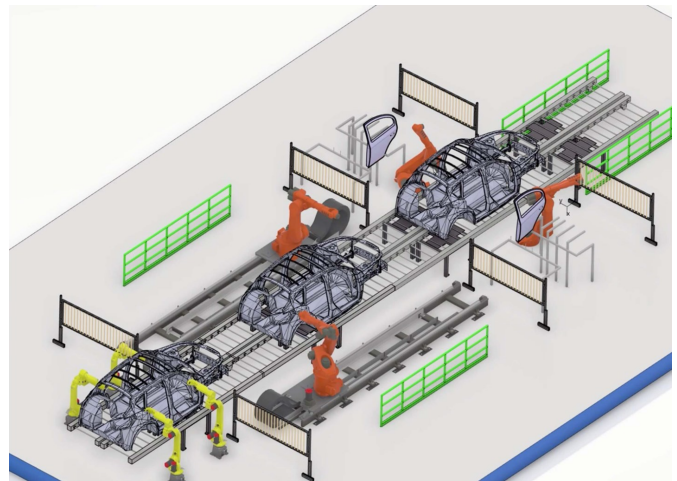


Figure 2. Finding design problems and faults by simulating the manufacturing process before completion results in time and money savings.

Ordinarily, Real Commissioning is done after the completion of engineering, procurement, and assembly. That is because, conventionally, VC is used as a means to test and troubleshoot the integrated planned manufacturing system; hence, it is conducted after the system is already built (Hoffmann et al., 2010). Therefore, design problems and faults often remain undetected until Real Commissioning is completed. Correcting these problems during commissioning and the early production phases of the system are time consuming and costly, leading to time delays and increased costs for all parties involved (Lee, & Park, 2014). Figure 3 shows that for earlier changes in the design costs less than changes in an advanced stage of the project. In addition, the software used to perform the task is an extra expense that is generally used only occasionally for this specific purpose.

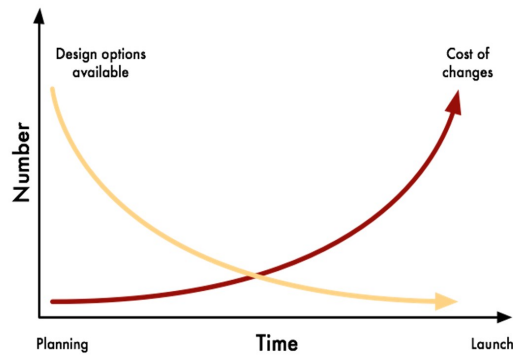


Figure 3. Later changes cost more than early changes.

Normally, Virtual Commissioning software is used to maximize productivity and accuracy and to minimize the system's wasted time and money. Consequently, the system needs at least one worker that is skillful and specialized in that software, which means that more money is spent. Some examples of the software used for VC are VCx, Xcelgo's Experior, SimulationX, and Tecnomatix. In this paper, the author introduces commissioning through simulation, a more economically viable means of Virtual Commissioning. With increasing computer technology, VC can also be applied to large-scale manufacturing systems (Lee, & Park, 2014). Even though some companies or industries are using VC, the majority have thus far neglected its benefit.

## Virtual Commissioning Through Simulation

To allow VC through simulation, a simulation model of the manufacturing system, also called digital twin, is used during VC and before building the system (Hoffmann et al., 2010). Figure 4 shows how this digital twin can be generated and coded, based on the available data of the machines used during the manufacturing process. The objective is to detect and correct the errors generated during planning, design, and programming. This can reduce the time spent on debugging and eliminating errors in control systems by 70% during Real Commissioning (Hussain, & Semere, 2013) and reduce the costs by 40% (Guerrero, López, & Mejía, 2014). Other advantages of VC through simulation include:

- By means of VC, manufacturing systems, real plants as well as their related control programs, can be tested before being constructed.
- Debugging and correction efforts will be significantly reduced during implementing and running the real industrial applications.
- Economically, simulation can dramatically reduce the expenses spent on VC. Commissioning simulation using CAD software does not require a highly skilled workers to perform it.

- CAD software is well-known and available in the manufacturing industry. It can be utilized for many purposes.
- Training of workers can start before the actual installation, which results in an earlier manufacturing start.

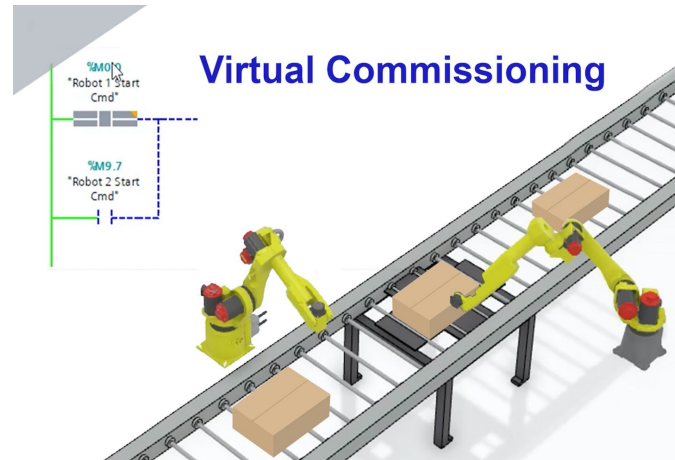


Figure 4. Plant Visualization, where the 3D-model is animated using the simulated values of the behavior.

## Methods

To show the advanced control code efficiently, a dynamic behavior model should generate a model-based interface between the controller model and the virtual cell, or between the controller devices and the virtual cell. By using a functional block library, the dynamic behavior model alters controller commands to virtual cell emulator commands. A simulation situation assists to effectively validate the serviceability of a controller model and a virtual cell. From CAD information, in order to simulate an object, manual hierarchical configuration of devices (robots, sensors, tools, or effort pieces), parts (single static units such as joints of a robot), and elements (describing the geometry such as cylinders, spheres, or points) is the important step in generating the model. Figure 5 shows a fully generated model with all robots, sensors, conveyers, the parts, and so on.

## Functional Modelling

In the functional modeling phase, actuator functions can be manually allocated, such as translation, rotation, gripping, etc., and sensor functions to selected segments of the geometrical models, which results in the definition of incorporated functional models such as cylinder, sensor, gripper, and so on (Berndt, von Lukas, & Kuijper, 2015). In order to complete the functional modeling, specific data are required. This includes a detailed layout of the production cell with exact locations of resources and relevant equipment or specification of the material flow on the shop floor. During functional modeling, first design problems—for example,



the interference of two or more robots to each other, the collision of a robot, or its load with the surroundings—can be detected. Solving these problems might require changing the design, the movement, or order of the robots. Being able to solve these problems before installing the machines and robots saves valuable time and space.

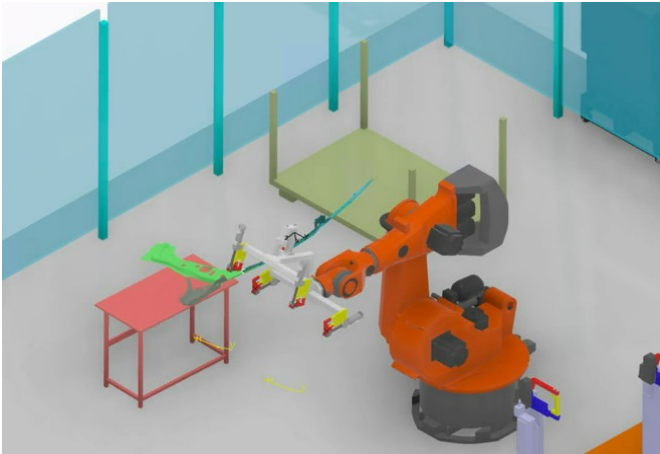


Figure 5. Generating the simulated model including robots and sensors.

## Electrical Modeling

Figure 6 shows how VC can be used to validate the PLC ladder logic before Real Commissioning. For the overall electrical modeling, manually adding electrical inputs/outputs to the functional models for later connection to inputs/outputs of control schemes is necessary to generate full mechatronic models. Controller models are designed to control expected manufacturing equipment by managing data and signals in order to get the preferred control behavior. Figure 7 shows the elements for controlling the virtual twin with a real PLC shows. Compared to the conventional design procedure, the electrical and mechanical design

phase can be performed simultaneously. Electric designers can start working earlier, not needing to wait for completion of the mechanical design phase, resulting in a faster time to market. Additionally, independence from the physical system's location and installation time is particularly beneficial. Especially in times of a pandemic, this independency can secure the time schedule and health of employees. Being able to start the electric modeling at an earlier stage also allows an increased number of test scenarios.

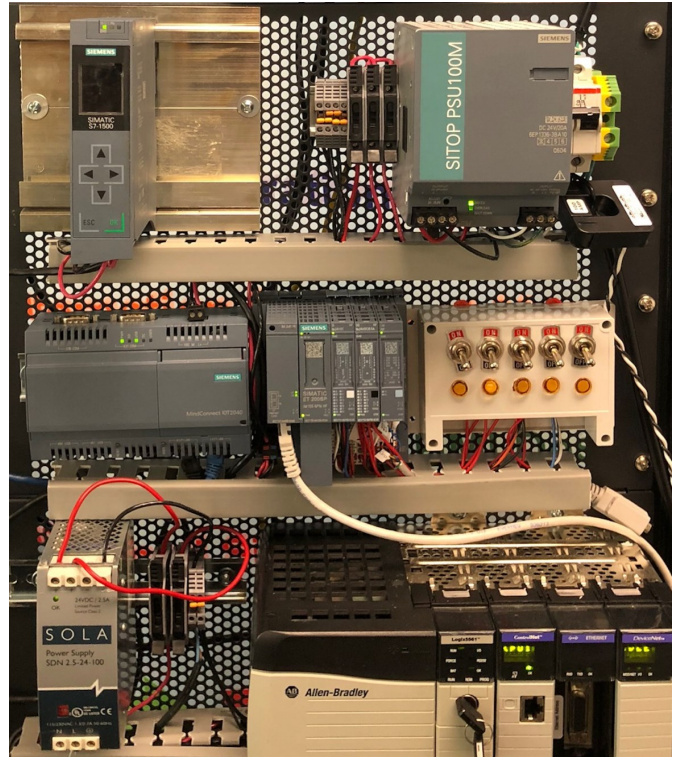


Figure 7. Elements that will be included in the simulation, comprising the forwarding of their signals.

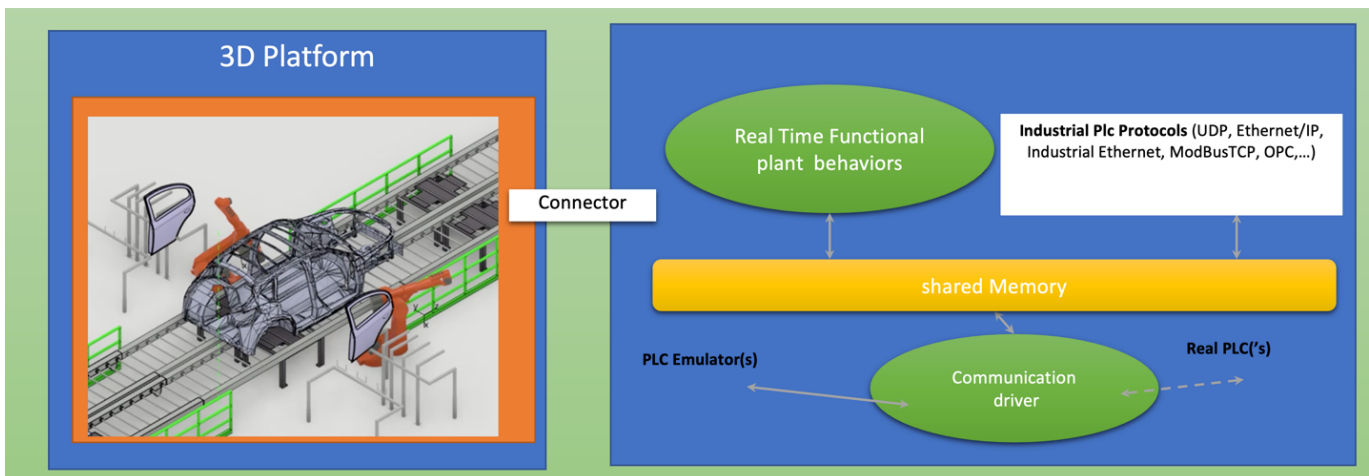


Figure 6. Control Architecture for the system under examination.



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## Conclusions

Virtual Commissioning (VC), the use of a hardware controller such as a programmable logic controller (PLC) with a virtual model, could be improved as a process to enhance the efficiency of the manufacturing system. Normally, VC is done after the construction of the system; therefore, it could require fundamental changes to the built system instead of minor changes that cost more money and time. In this paper, the author proposed a solution that can be used to avoid major changes, as VC is done before or during the construction of the system through simulation. The proposed method uses CAM software to integrate and test each phase of the construction of the system before it gets implemented. This includes:

- Designing parts
- Assembling parts
- Simulate constraints and mechanical behaviors
- Simulate control logic

Each phase could be examined and analyzed by commissioning simulation before implementing it on the floor. After that, a complete integration test is run to determine any system process flow in the virtual system. Finally, based on the test, the system can be applied or modified, saving time and money either way. The most popular operators are OEMs and plant vendors, who use VC for the validation of control schemes, as well as service preparers, who are restricted in the domain of VC and get subcontracted to carry out VC. However, VC will not replace Real Commissioning, as malfunctions can occur due to installation errors.

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## Biographies

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# ATTENDANCE TRACKING SYSTEM USING DEEP LEARNING-BASED FACIAL RECOGNITION

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## Abstract

In this paper, the authors present a capstone design project for a team of electrical and computer engineering senior students. The attendance tracking system consisted of both hardware and software. The hardware included the Nvidia Jetson Nano microcomputer, a camera, and a display. The software included a face-recognition package under the Python environment and a database. A 3D-printed container was designed to hold all of the components. As facial recognition was the foundation of the project, the authors cover here both the history and the basis of facial recognition, comparing traditional and deep-learning methods followed by system design and integration. The system was tested and proved to be effective. First, it was a device that could be put at the door of the classroom for attendance checking but which would not take time away from the instructor during class. Second, the results were automatically recorded in the database in order to avoid human marking errors. This design dramatically reduced the time for instructors who needed to take the attendance, especially with a large class size. And the resulting accuracy of the facial recognition satisfied the application's needs.

## Introduction

Facial recognition is a challenging task in various environments for different applications (Zhou, Liu & Huang, 2018). There are both traditional methods and machine-learning methods. Recently, deep learning has provided a new paradigm utilizing training datasets to improve performance (Peng, Wang, Li & Gao, 2021; Wang and Deng, 2021). From this current study, the authors present one example that utilized it for taking class attendance. As a senior design project, students also learned the fundamentals of computer vision and face-recognition algorithms. Facial recognition has been around for years now. The dawn of facial recognition was in the early 1960s, but the technology was unpopular, due to the lack of computing power and popularity. The earliest pioneer of facial recognition was Woodrow Wilson Bledsoe. In 1964, Bledsoe began to work with computer programs to recognize human faces. Due to the project's funding originating from an unnamed intelligence agency, much of his work was never published. However, it was later revealed that their initial work involved the manual marking of various "landmarks" on the face, such as eye centers, mouth, etc. These were then mathematically rotated by a computer to compensate for pose variation. The distances between landmarks were also automatically computed and compared between images to determine identity (Bar-Ilan, 2008).

In today's modern age, digital technology developments enable powerful computing facilities to support booming data analytics. Artificial intelligence (AI) methods like convolutional neural networks (CNN), Markov decision process (MDP), and natural language processing (NLP) are finding their ways into many real-life applications. Internet-of-Things (IoTs), edge computing, object detection, and facial recognition are now highly developed technologies. In the category of machine learning (ML), deep learning (DL) plays a vital role in modern-day facial recognition. Deep learning uses ML algorithms and large datasets to train deep neural networks for enhanced accuracy. In this study, the authors focused on the deep-learning method of facial recognition with hardware implementation to build a stand-alone attendance-tracking system.

Besides facial recognition, this project also included the practice of: 1) embedded systems design, which dominates computer engineering curricula—not only software programming, but also hardware skills are required for a successful design, and 2) makers space as a pedagogy to improve undergraduate engineering education. So, the output of this design was not just a prototype, but a fully functional and marketable product. Besides acquiring the knowledge of machine learning and facial recognition, students also achieved the integration of the different components in one embedded unit. The results showed the success of the system design and implementation.

## Previous Work on Facial Recognition Traditional Methods

Before the age of deep learning, there were numerous traditional mathematical methods for facial recognition. The major steps were to detect faces in the image and then identify the face from pre-existing collections. Of course, many techniques, such as feature extraction, dimension reduction, and de-noise were used in the completion of the aforementioned two steps. Under signal processing, there are various classifiers in the identification and verification of human faces. The performance of an algorithm depends on the conditions of training data and circumstance changes. High accuracy is not the only factor in determining the performance of an algorithm. Eigenface and Fisherman methods are two examples used in facial recognition. They have advantages and disadvantages, which are further developed with a combination of principal component analysis (PCA) algorithms, linear discriminant analysis (LDA), independent component analysis (ICA), and so on. Various existing studies will help in determining the optimal traditional method for facial recognition.

To achieve recognition automatically, a face database needs to be created. For each person to be recognized, several images with different poses are collected and stored in the database (Setiowati, Franita & Ardiyanto, 2017).

## Deep Learning Approach

Deep learning is one type of machine learning methods that trains a computer to perform human-like tasks, such as recognizing speech, identifying images, or making predictions. It sets up basic parameters about the data and trains the computer to learn on its own by recognizing patterns using many layers of processing (Qu, Wei, Peng & Du, 2018). An important deep-learning algorithm applied to facial recognition is convolutional neural networks (CNNs/ConvNets). CNN has layered architectures to check the degrees of shift, scale, and distortion (Setiowati et al., 2017). Figure 1 illustrates one example of a CNN structure. Most facial-recognition systems follow a similar algorithm structure like early ones with modifications to improve the algorithm's accuracy and performance. There are both advantages and disadvantages to using deep learning for facial recognition. Advantages include robustness to resolution and high accuracy, while disadvantages include complex computing and non-descript imaging (Geitgey, 2019).

## System Design

This was an undergraduate senior design project for a group of electrical and computer engineering students. The purpose of this project was to reduce the amount of time necessary for processing attendance and to increase the accuracy of the reporting. Authors utilized a deep-learning

method in computer vision to develop the attendance-tracking system. Both software and hardware designs were involved. The software design was based on open source packages, while the hardware was based on Jetson Nano, a powerful microcomputer platform.

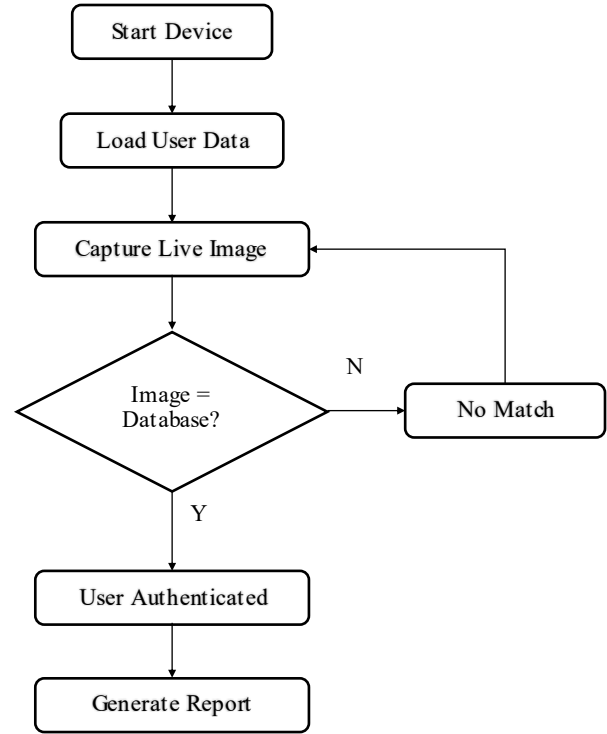
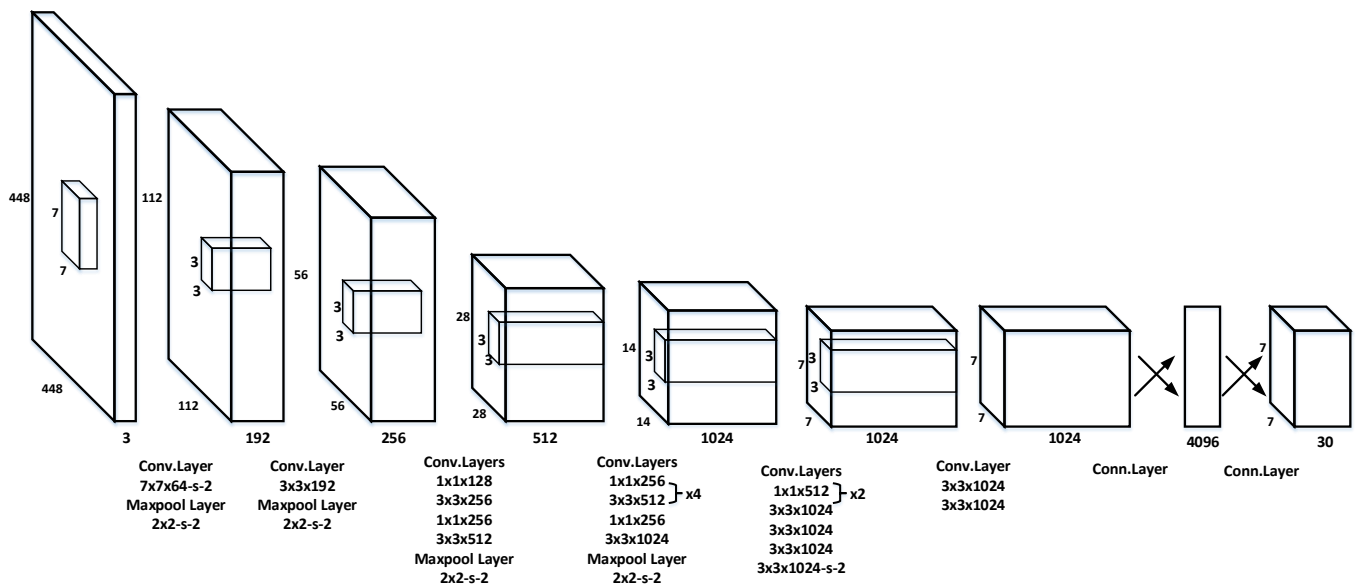


Figure 2. Flowchart showing the software process.



## Software Design

This system was built in the Python programming environment and there were a few open source libraries, such as OpenCV and Dlib, which were selected to perform the facial-recognition task. The software program used in this current study consisted of several modules: image capture, facial identification and recognition, database access, and recording. Figure 2 illustrates a brief flowchart. The Python programming language is very popular in applications like image processing and machine learning. To be able to establish the facial-recognition system, a collection of images is first stored in individual folders and labeled by the persons of interests. This purpose of this procedure is to build the training pool; different poses of each person are collected in order to improve the accuracy. The name from each file was extracted and stored in a list, which would come in handy later for the attendance report. Then, the cv2 function “imread” was used to read in each image from the folder. The face encodings from the pictures were searched from the saved datasets. This was accomplished by using the face-encodings function provided by the facial-recognition Python library. The image was then converted to the RGB format before the encoding took place, then the results were stored in a list.

To perform facial recognition, a live video stream was taken from the camera. Each frame was extracted from the video and fed into the system. As done previously, the images were resized to match with the processing requirement, then they were converted into the RGB format. Before facial recognition, facial identification was performed in order to locate the position of the face in the image. Those processes were accomplished by the functions “face locations” and “face encodings.” Next, a function named “compare faces” was invoked in order to compare the encodings of the list of known individuals to the encodings from the live feed frame capture. The function compared a list of facial encodings against a candidate encoding to see if they matched. Euclidean distance was used to compare each face, and the minimum-distance value indicated the closest match. Thus, a threshold needed to be set before the call function “face distance.” Typically, 0.6 was chosen, which would lead to the best performance. As a result, the “compare face” function would return the index, which pointed to the known face list created earlier.

To improve the display’s clarity, the position values obtained from the “face locations” were utilized in order to draw a rectangle around the face using the cv2 function “rectangle.” At the same time, the identified person’s name, which is the label from the folder, was also shown under the rectangle. To store the attendance data obtained, a MySQL database was implemented. MySQL is a database management system that allows one to manage relational databases. It is based on open source software and is owned by Oracle. One database called “Attendance” was created containing a table with two values: Name and Time. When an individual

was correctly identified, the system would pass the name of the individual and the time of recognition to the database. The database was hosted locally (at the time of this current study), but it could be easily changed to a remote recording later on. A machine learning-based, facial-recognition software package and a MySQL database were the two major software selections. After determining the software of the system, the next task was to choose the hardware.

## Hardware Design

Recently, embedded systems, such as a computer-based control system, have become more and more popular. The proposed facial-recognition system in this current study was a microcontroller/microprocessor-based embedded system to fit for the desired portability. There were also many choices of microcontrollers/microprocessors on the market, which made the selection very challenging. One has to satisfy the power, computing, storage needs, as well as the cost range, to have a competitive design. Adam Geitgey, one of the main contributors to the facial-recognition Python library, stated, “... the Jetson Nano supports the exact same CUDA libraries for acceleration that almost every Python-based deep learning framework already uses.

This means that one can take an existing Python-based deep learning app and often get it running on the Jetson Nano with minimal modifications and still get decent performance” (Geitgey 2019). That statement gives a hint of hardware selection. Thus, the main hardware of the system used by the authors was Jetson Nano, as introduced below, which proved to be successful. The Jetson Nano micro-computer system has a quad-core, 64-bit ARM CPU and a 128-core integrated NVIDIA GPU. It delivers 472 GFLOPS of computing performance with 4GB LPDDR4 memory in an efficient, low-power package with 5W/10W power modes and 5VDC input. The NVIDIA Jetson Nano developer kit lets one run multiple neural networks in parallel for applications such as image classification, object detection, segmentation, and speech processing, all in an easy-to-use platform that runs on as little as 5W.

Table 1. System hardware selections.

Function	Parts Specification
System Control	Jetson Nano Microcomputer, a quad-core 64-bit ARM CPU, 128-core integrated NVIDIA GPU, 4GB LPDDR4 memory, low-power package with 5W/10W power modes and 5V DC input.
Camera	Intel® RealSense™ depth camera D435
Display	7-inch HDMI LCD (H) 102 x 600 IPS Capacitive Touch Screen LCD
Container	Use AutoCAD to design and 3D printer to print the product.



After the Jetson Nano microcomputer was selected to be the major hardware to control the system, the search for compatible devices that could capture images fed into the microcomputer, locally display the results, and remotely store the records became crucial. After searching, comparison, and discussion, all of the parts from Table 1 were acquired. Figure 3 shows the connections of each hardware component.

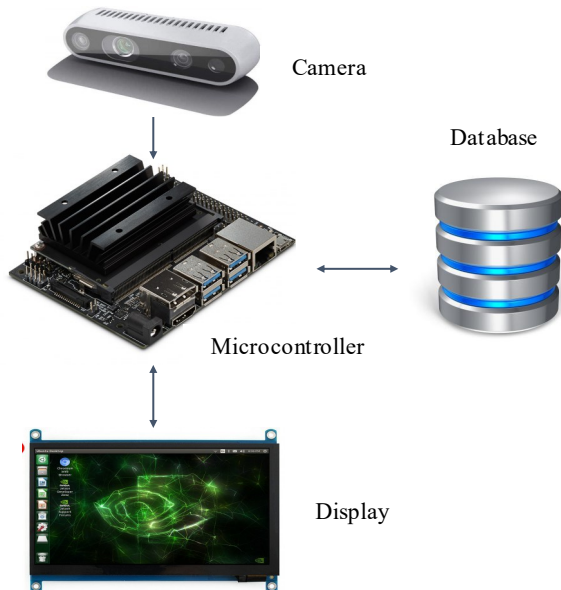


Figure 3. Component connections of system.

The Jetson Nano utilized an external camera for image-processing applications. Various cameras were considered for this application. It is evident that, for facial recognition, high-quality images were desired. There are many powerful cameras that are compatible with the Jetson Nano. The decision was based not only on performance, but also cost. The Intel RealSense depth camera D435 is a stereo solution, which offers quality depth for a variety of applications. Its wide field of view is perfect for applications such as robotics, augmented, and virtual reality. In selecting this camera for this project, the system then met the performance standards as well as achieved the cost effectiveness desired by the authors.

To make the system user friendly, the project team searched for a touch screen display, and ended up with a 7-inch HDMI LCD (H) 102 x 600 IPS capacitive touch screen LCD Display HDMI module. This LCD display can show the facial-recognition results in real-time, and users can select different options provided by the system using the touchscreen feature. Of course, it is compatible with Jetson Nano. Besides the hardware selection, a 3D printer was used to produce the housing to hold all of the hardware together as one unit. The 3D printer was sponsored by a Department of Education-funded project that teaches students the

concept of “Maker Space” and enables students to add more hands-on experience on the integration of an entire unit after the proof-of-concept stage. This design, then, resulted in a complete product, ready to be used commercially. Figure 4 shows the entire assembled system.



Figure 4. System Appearance

## Results

The system was successfully built with hardware residing in the 3D-printed case and software installed with a test dataset. It was achieved by recognizing a small group of students and recording their attendance in the database. The application identified numerous pictures of individuals and recorded their attendance as well. Figure 5 shows a sample output of a successful recognition case shown on the LCD screen.

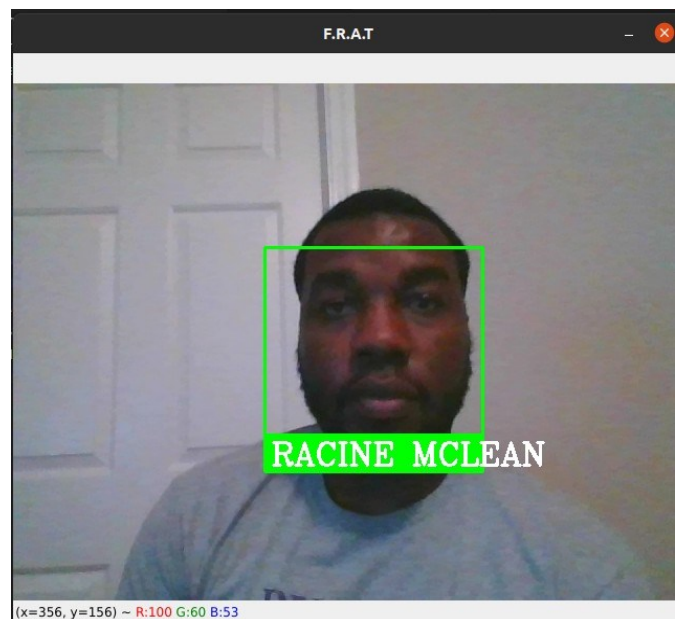


Figure 5. Test case: system recognizing Racine McLean.

Due to the COVID-19 pandemic, access to other individuals to test the system was limited. However, the system was successful in recognizing all senior design team members, most of whom were African American male students. For privacy reasons, the individual names were not used in the database. Each individual was given a number their attendance randomly recorded. Figure 6 illustrates the attendance results recorded in the database. Though the testing from the live camera feed was limited due to remote learning in the current semester, the project team was able to identify some faults with the facial recognition and provided solutions. For example, as the testing group was mainly from one ethnic group—African Americans—the similarity of the faces was high. If the default tolerance value of 0.6" "face distance" calculation were kept, multiple matches with individuals in the testing pool would be obtained. So, a lower tolerance value was needed to make the facial comparisons stricter. After several experimental trials, the authors observed that, by reducing the tolerance value to 0.52, much more accurate recognition results could be achieved.

Name	Time
RACINE MCLEAN	22:30:24
INDIVIDUAL TWO	22:30:36
MARK ZUCKERBERG	22:30:44
INDIVIDUAL FOUR	22:30:46
INDIVIDUAL ONE	22:30:53
INDIVIDUAL THREE	22:30:58

6 rows in set (0.00 sec)

Figure 6. The recorded attendance of individuals.

In Figure 6, a widely known name, Mark Zuckerberg, is shown in attendance. One might be wondering whether Mark used this system. Well, unfortunately, the answer is no. It was because a picture of Mark was used in front of the system to see if he could be recognized, which he was. With the system recognizing an individual face from a picture, one might see this as a failed test case. This was, in fact, not the case, since the system was only required to recognize a face and record the person's name and time seen. Whether it was an actual person standing in front of the camera or an image held up to the camera, both were acceptable outcomes. However, it does bring up the issue of fooling the system by using student photos. As the camera had the feature of detecting depth, adding this feature could get rid of this photo-recognition case.

## Conclusions and Future Work

In conclusion, the tasks of developing an automatic attendance tracking system were achieved. The designed system was able to recognize a face, identify that individual, and record that person's attendance in a MySQL database.

This system could apply to many other applications and not just attendance tracking for students. It could be used to grant access to secure buildings and rooms or even access to highly secured neighborhoods. Both the traditional facial-recognition and deep-learning methods were discussed in the paper. One can see the reason for shifting from the traditional hand-calculation method to the deep-learning approach. From the evidence from this study, one can conclude that the deep-learning method for facial recognition was the best solution thus far. Daniel Saez stated, "...facial-recognition systems based on CNNs have become the standard due to the significant accuracy improvement achieved over other types of methods" (Trigueros, Meng & Hartnett, 2018). Every day, advancements are being made in the field of deep learning—it is advised that everyone pursue an engineering degree to get into AI and machine learning, as this is the future.

There are a few additions that the authors would make in order to take this project to the next level in the future. First, the attendance list could be made accessible to a remote data cloud as a backup. Secondly, a user portal could be created so that the professors or users with administrator access can retrieve data without querying the database, since most users will not be technical personnel. Thirdly, the depth features available with the Intel RealSense Depth camera could be utilized to avoid individuals having to record their pictures for attendance.

## Acknowledgement

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## Biographies

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# DIGITAL EDUCATIONAL MODULES DEVELOPMENT FOR THE CAREER AND TECHNICAL CYBERSECURITY PATHWAYS DURING THE COVID-19 PANDEMIC

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## Abstract

Virtual learning has been used now for several decades, but it has never had a bigger impact on student learning than in the era of the COVID-19 pandemic. Universities and schools faced shutdowns all around the world, and teachers had to adapt rapidly to online mode of instruction. Many educators were faced with a triage approach with no previous experience in distance learning, a lack of resources for professional development, and already existing shortages of current educational modules that could assist them in their day-to-day jobs. This gap was especially evident in areas such as career and technical education (CTE) in which there was a gap in the training and educational materials available for K-12 teachers in emerging technology fields such as computer science and cybersecurity.

These problems are related to various issues, such as the lack of teacher preparation, constant changes in technology, curriculum and educational framework developments led by the various institutions dictating the nature of education, and moreover, the vast growth in the demand for such instruction, which presents challenges in meeting those growing demands. In this paper, the authors present one curriculum development effort for CTE high school programs focused on computer science and cybersecurity via a grant by the Perkins Innovation Project funded by the U.S. Department of Education and supported by engineering technology, electrical engineering, and industrial technology educators.

## Introduction

The main problem that researchers are trying to solve is the lack of current educational resources available in the area of CTE cybersecurity for high school teachers that are current in their skillsets (according to the industry need), based on Virginia Department of Education competencies. The area of cybersecurity is facing rapid growth and currently there is a lack of sufficient materials available for CTE teachers to teach all cybersecurity courses in the pathway. The research question for this study was:

*Would a partnership between the CTE department, university, and industry improve hands-on CTE cybersecurity educational modules that can be easily integrated into virtual or in-person high school curricula?*

*Hypothesis: Online access to the hands-on CTE cybersecurity educational modules accessible to CTE cybersecurity teachers will lead to a better understanding of cybersecurity careers and pathways.*

*Research Objective: Develop, assess, and improve hands-on CTE cybersecurity educational modules that can be easily integrated into a high school curriculum.*

Currently, there are a plethora of resources and educational modules being developed nationwide for various math and science topics that are funded by various federal agencies. Many of these modules are scattered and they are not integrated into specific pathways, or into the multiple classes, at the state level. The main research gap is present in educational programming and support available for the area of career and technical education, which is mainly supported by the U.S. Department of Education Perkins 5 Act funding. Even CTE teachers' salaries are funded differently than other high school teachers, and each year school districts have to make sure that they apply for these funds and that these funds are available for CTE pathways such as cybersecurity.

However, there is no related work that was documented in terms of engaging CTE departments, university, and industry on one such curriculum development project through an integrated approach. Work on this current study was done with the support of the CTE department from a local Norfolk Public School district. Modules were then improved, following feedback from an industrial advisory board and with the help of instructional developers. Modules were distributed to all cybersecurity CTE teachers in the Commonwealth of Virginia by Judith Sams, Specialist, Business & Information Technology and Related Clusters - Virginia Department of Education.

## The Impact of COVID-19 On CTE Teachers

The COVID-19 pandemic has had an enormous impact on work, entertainment, travel, and education (Radha, Mahalakshmi, Sathis Kumar, & Saravanakumar, 2020). In addition, recommended standards, such as social distancing and physical distancing, by the World Health Organization (2019) increased its impact on lives even more (Aliyyah, Rachmadtullah, Samsudin, Syaodih, Nurtanto & Tambunan,



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2020). These regulations were also extended by governments and local administrations to include working from home, homeschooling, virtual learning, stay-at-home orders, etc. Due to COVID-19, many K-12 students in the U.S. were also missing access to face-to-face education. The general public shared a common concern about student achievement, as well as the possible negative effects on widening the gap between high- and low-achieving students. In a study by Aliyyah et al. (2020), the authors investigated the impacts of COVID-19 on student achievement and what it may mean for educators.

The results indicated that: 1) students might be substantially behind, especially in mathematics; 2) students are likely to enter school with more variability in their academic skills than under normal circumstances; and, 3) under normal circumstances, students who lose the most during the summer tend to gain the most when back in school, but this may not hold during COVID-19 instruction time. Multiple states in the U.S. have developed a web platform and related websites to share the most up-to-date information and resources with teachers and communities. For example, the Virginia Department of Education (VDOE) guidance for the 2020-2021 school year, including Virginia's return to school plan, school reopening frequently asked questions, and Virginia's phase guidance for reopening schools (Aliyyah et al., 2020). Universities and school districts developed web pages that would address special guidelines related to online learning and to different support materials needed for online instruction.

The pervasiveness of the COVID-19 pandemic has significantly increased since it started, making it difficult to return to everyday life. The long-term impacts of the COVID-19 pandemic are still uncertain. One of those impacts is related to the significant way it affected the education process. Students would be the most affected group, due to a lack of face-to-face education during COVID-19. The lockdowns in response to COVID-19 have interrupted conventional education in most countries, with the majority lasting at least ten weeks (Aliyyah et al., 2020). However, students should still gain enough knowledge, skills, and attitudes, as well as values and social interaction that would be otherwise provided by the educational systems to sufficiently drive subsequent generations.

According to a report released by UNESCO, 132 countries worldwide have been implementing nationwide closures due to the COVID-19 pandemic, which affected 1,048,817,181 students (i.e., 59.9%) of all enrolled students at the pre-primary, primary, lower-secondary, and upper-secondary levels of education, as well as in higher education (Aliyyah et al., 2020). Various studies are now trying to understand the impacts of student learning, while educators have been forced to determine how to provide distance learning even though they did not have previous experience or much support (Hoffman & Miller, 2020).

The COVID-19 pandemic has severely impacted educational systems from elementary schools, middle schools, and high schools, and post-secondary institutions. While some universities quickly responded and replaced face-to-face lectures with virtual learning and educational tools, other schools had difficulties in terms of adaptation due to a lack of teachers' and students' experience, resources, and supportive environments. From this current study, the authors present the development of digital educational modules for virtual learning in the computer science and cybersecurity pathway in high schools during the COVID-19 pandemic. These modules were developed for high school CTE teachers by a team of undergraduate students, graduate students, and engineering college professors with the help of educational professionals. All modules were revised by the high school teacher practitioners, reviewed by industry practitioners, and finalized by a professional instructional designer.

## Learning over Distance Education

Virtual learning is defined broadly in many ways. Although those learning forms look similar, they are different in terms of the aspects of learning and teaching. They vary greatly in terms of adequate technical support and available facilities, especially during the COVID-19 pandemic. Many of the professors, teachers, and students have to participate in the teaching and learning process in virtual environments, while facing issues with internet connectivity, up-to-date devices, noise at the places from where they were participating, and other issues that were not encountered previously in well-established distance learning programs.

e-Learning refers to the use of electronic technologies, such as the world wide web, an intranet, or other multimedia materials, for learning and teaching, which can be conducted by means of electronic media with or without the use of the internet. It is also considered a type of online learning and has been widely used for the last decade with advances in technology and changes in society. There are a variety of e-learning forms—standalone courses, learning games and simulations, mobile learning, social learning, and virtual classroom courses (Horton, 2011). e-Learning has been used for a relatively long time. However, it is still considered immature, due to a lack of organizational aspects of teaching and only focusing on supporting learning. This causes students to become de-individualized and demoted to a non-critical, homogenous users. To deal with these drawbacks, various researchers have suggested creating individual e-learning materials using flexible, multidimensional data models and individual content in order to improve the success of e-learning systems (Tavangarian, Leypold, Nölting, Röser & Voigt, 2004).

Web-based learning refers to the use of a web browser for learning. It has been widely used both as a learning tool to

support formal programs and as a means of delivering online learning programs. In the literature, two main issues are addressed in web-based learning environments, namely the design of the learning materials and the technology. In the last decade, teachers have gained experience in the design of learning materials (online activities, games, animations, and simulations) with easy-to-use software tools. These materials also improved learning and made it more enjoyable for learners (Tavangarian et al., 2004). With advanced information and communication technologies, many technological barriers, such as limited and poor communication access and slow downloading of images and videos, are eliminated in web-based learning environments.

However, learner needs and experience must still be considered. Appropriate technology and reasonable computer skills are needed to get the best out of web-based learning, which, during the COVID-19 pandemic, led to the use of various online platforms for different courses. Figure 1 shows some of the various online systems, for example Clever, used by a number of schools in which students would have access to landing pages of various online platforms that they would use for schoolwork, such as Google Classroom, Canvas, Google Drive, Office 365, etc. They also had links to online textbooks, applications, and popular apps used in the instruction.

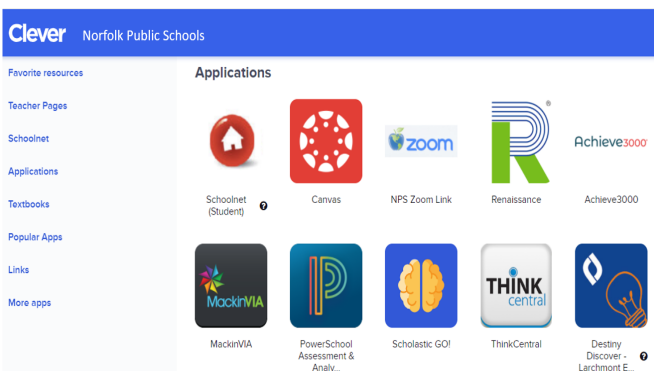


Figure 1. Clever landing page of Norfolk Public Schools.

Online learning is usually described as access to learning experiences via the use of some technology or as a more recent version of distance learning, which improves access to educational opportunities for learners (Moore, Dickson-Deane & Galyen, 2011). This form of virtual learning became more popular with internet technologies and is associated with electronic content available on a computer/mobile device. Online learning can be conducted through programs or apps installed on a user's devices. It provides many advantages, such as increasing student engagement, making it easier to differentiate instruction, which saves time with planning and grading. However, online learning relies on students having access to technology in school on a regular basis. Online learning works best for middle and high school teachers who want to provide different ways for their students to learn (Moore et al., 2011).

Distance learning is described as the effort of providing access to learning for those who are geographically distant. Distance learning is an excellent teaching method, because they need the flexibility to contend with competing priorities (Galusha, 1998). It does not have to be conducted with electronic and web-based technologies. It can be conducted through the use of audio-video media, such as videotape or DVDs (Holden & Westfall, 2007). Distance learning provides greater flexibility for students to work at their own pace and review work as needed. With the development of digital technologies, distance learning is increasingly associated with online learning. Distance learning is a method for delivering instruction solely online and does not include any in-person interaction between teachers and students. It is not feasible to use distance learning if the students do not have access to devices or the internet at home. Distance learning typically works best with older students who have consistent technology access at home and will work responsibly on their own (Stauffer, 2020).

Blended learning is a type of learning that combines virtual and traditional forms of teaching (Kim, 2007). It covers online resources and allows control of the learning process in terms of time, place, and learning method. Blended learning is also used to describe learning that mixes various event-based activities, including face-to-face classrooms, live e-learning, and self-paced learning (Valiathan, 2002). Blended learning can also be viewed as a kind of relic, symbolic of the gap between traditional education and connected and digital learning. It includes face-to-face group work in a classroom, then going home to analyze that work and turning in an assessment individually or taking a course online, then receiving face-to-face tutoring between online lessons (TeachThought, 2020). Blended learning provides many advantages in terms of flexibility, effectiveness, teacher empowerment, engagement, and differentiation. However, it requires training and support in technology usage for teachers, advanced information and communication technologies, and tools to provide the required environment of a blended learning classroom (Walker, 2018).

Virtual learning is a type of educational technology environment that is typically offered as a web-based learning platform utilizing computers and internet technologies. It is associated with things like online courses, tools, simulations, e-textbooks, and e-workbooks. It consists of many educational components, activities, and interactions, such as content, curriculum mapping and planning, learner engagement and administration, communication and collaboration, and real-time communication—live video conferencing or audio conferencing (Stiles, 2000). For virtual learning, all teaching activities are carried out in an online environment—either self-paced (asynchronous) or live web-conferencing (synchronous)—in which the teacher and students are physically separated (Skylar, 2009). It provides many advantages over traditional forms of education, such as remote access, an individualized learning process, a safe and secure learning environment, flexible learning in terms

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of time, location, and place, cost-effectiveness, time-efficiency, and scalability. Many of these learning modes have been used by various institutions, either in high schools, colleges, or universities. Some distance learning occurred with paper-based packets in the Norfolk Public Schools at the end of the 2019-20 academic year, when the COVID-19 pandemic caused schools to close and while many students still did not have access to the internet or have reliable devices to assist them in the real-time distance learning.

Some of the modules developed during this project were designed for “Learning in Place” paper-based packets that were distributed to high school students. They were supposed to be stand-alone, paper-based modules that could be completed independently by students. One of the main issues was related to the nature of the computer science and cybersecurity disciplines themselves, as they are heavily related to the use of computers and some informational technology (IT). However, back when they were in school, several members of the research team did learn the basics of programming and computer science without the use of computers, and they went back to the drawing board and rethought the approach of teaching intro to computer science and cybersecurity courses. The main idea was to take the students back to the basics, back to the motivation behind the cryptography and cyphers, back to the basics related to programming and the way networking was structured and start from there. There was a need to investigate what kinds of things should be taught at each step of the computer science and cybersecurity pathway and how this high school knowledge was connected to the profession of engineering and engineering technology.

The main idea was to teach these topics through application-based activities and hands-on approaches and to expose the students to industry and academics through a series of visiting speakers whom they would otherwise not meet. All five Norfolk Public Schools high schools have students from qualified opportunity zones that have populations from low-socioeconomic levels (Jovanovic et al., 2020), and many students did not have adequate devices and internet access when the pandemic started.

## Policy Issues in Teaching Computer Science and Cybersecurity

Attention to cybersecurity education has been growing at the federal level since January 2008, when President George W. Bush launched the Comprehensive National Cybersecurity Initiative (CNCI). The following year, President Barack Obama conducted a review of security issues and efforts and implemented 12 strategies in support of the CNCI (The White House of President Obama, 2011). In February of 2014, then Governor of the Commonwealth of Virginia Terry McAuliffe established Cyber Virginia and the Virginia Cyber Security Commission through Executive Order 8.

Presenting recommendations to foster an improved cybersecurity workforce pipeline was among the responsibilities of the commission. It was determined that there was an immediate need to identify the role of K-12 education in building the cybersecurity pipeline, as well as to help schools at all levels—elementary, middle, and high school—prepare students for the cybersecurity career field. Since cybersecurity affects all occupations, CTE pathway courses were customized for each of the 16 career clusters. Virginia developed a cybersecurity pathway to be implemented in middle and high schools (Virginia Department of Education, 2016). In the fall of 2017, high school students could enroll in one of four new pathways: Programming and Software Development, Health and Medicine Sciences, STEM/Pre-Engineering Technology, and Network Systems.

## Standards and Interoperability

The CTE Federal Program Monitoring Review System (Virginia Department of Education, 2020a) was designed to focus on continuous program improvement and student achievement. The Federal Program Monitoring Review System consists of three phases: Phase I requires the school division to conduct a comprehensive CTE self-assessment on a six-year cyclical schedule and develop a program improvement plan, as needed, to address identified deficiencies and concerns; Phase II requires the VDOE to conduct an analysis of the self-assessment report and other relevant data that may include an on-site visit to review specific CTE programs; Phase III requires the school division to follow up on any identified deficiencies and concerns.

Superintendent Memo #162-19, Virginia Department of Education, dated July 10, 2020, states that the 2020 General Assembly is continuing state funding to support industry credentialing testing materials for students and professional development for instructors in science, technology, engineering, and mathematics-health sciences (STEM-H) CTE programs. This appropriation is from the lottery proceeds fund and included \$500,000 for fiscal year 2021.

## Tools and Systems in e-Learning of Computer Science and Cybersecurity

Norfolk Public Schools decided to focus on a distance learning approach of virtual learning that included the teacher, not just the facilitator. Various virtual learning tools were used: simulations, e-textbooks, e-workbooks, Virginia Cyber Range—a scalable, cloud-hosted infrastructure providing students with virtual environments for realistic, hands-on cybersecurity labs and exercises (Raymond, 2020), and resources available on other platforms, such as on cyber.org and code.org. In virtual learning, teachers are teaching synchronously, and they are not using asynchronously pre-recorded lectures. Students do have meetings with their teachers. They are also using MindTap accounts (Cengage, 2020).

At the end of the 2019-2020 school year, paper packets, called Learning-in-Place packets, included all necessary materials that students were using and Google Classroom and Google Drive materials and testing. The issue was that not all K-12 students in the Norfolk Public Schools had access to the internet and devices that they could use to participate in virtual learning. Because of this, initial learning happened through the paper-based approach. In the case of computer science and cybersecurity, the main problem was related to teaching something so dependent on information technology without information technology. The Norfolk Public School system has utilized the Google Suite of tools; however, they are currently moving to the Canvas educational learning management system. Other school districts in the area, such as Virginia Beach Public Schools and Chesapeake Public Schools, were already using Schoology (Schoology, 2020) and students already had mobile devices such as Chromebooks provided by the school system (Google, 2020).

## Content Development

In the fall of 2017, the Norfolk Public Schools were given permission by the Virginia Department of Education to offer cybersecurity fundamentals at all five of its high schools. The research team focused on the development of educational modules for two CTE courses under the Business and Informational Technology career cluster: Cybersecurity Fundamentals and Informational Technology (IT) Fundamental course (Virginia Department of Education, 2020b). These two courses were identified to be in the most demand and were implemented in all five Norfolk Public Schools. Both courses have a duration of 36 weeks and include the same set of competencies (1-38). These are: Workplace Readiness Skills for the Commonwealth of Virginia, Examining All Aspects of an Industry, Addressing Elements of Student Life, and Exploring Work-Based Learning. Competency 39 begins with the specific course competencies.

From June to August of 2020, Old Dominion University undergraduate and graduate students created Google Slides with educational modules based on the Virginia Department of Education's Career and Technical Education course competencies. The principal investigator created the template for all modules. They all had a unified design and information about the main stakeholders in each one of the slides. Each slide had one task/competence at the beginning. Some of them were expanded on multiple slides. Visuals were retrieved from Google Images with filtering of images approved for public reuse. Figure 2 shows an example of one such module. As the graduate and undergraduate students progressed with the development of the Google Slides modules, Norfolk Public Schools Career & Technical Education faculty, Dr. Deborah Marshall and Mr. Michael Crespo, provided feedback on each of the Google Slides, which was disseminated to all of the team members for further comments. Figure 3 shows one example of version control.

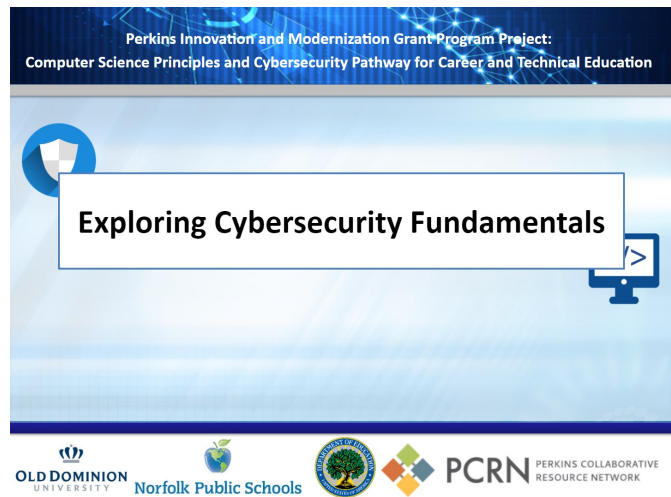


Figure 2. Example of one educational module in Google Slides.



Figure 3. Digital thread management was done with the version control in Google Docs.

Additional videos were created with hands-on activities and voiceovers. These modules were created to assist teachers with virtual, hybrid, or face-to-face versions of the Cybersecurity Fundamentals and Informational Technology (IT) Fundamentals courses.

## Data Collection and Analysis

The industrial advisory board had representatives that were IT and cybersecurity professionals from the following industries: government employees, shipbuilding, rotating machinery manufacturers, banking, consumer products industry, robotics industry, automotive industry, cybersecurity initiatives, and community college cybersecurity pathway experts. Additional professionals were recruited through the use of the social platform LinkedIn. The research team also worked with a professional instructional developer to finalize the modules and to implement suggestions from industry practitioners. The finalized modules were distributed to the CTE cybersecurity teachers in the Commonwealth of Virginia in April of 2021 through Judith Sams, Teacher Specialist for Business and Informational



Technology pathways, who works in the Virginia Department of Education. They were distributed through the project website <https://sites.wp.odu.edu/odu-nps-cs-cybersecurity-pathway-for-cte/> (Jovanovic, 2019). IT Fundamentals modules were reviewed by 33 industry participants and the cybersecurity modules were reviewed by five industry participants. Figure 4 shows one such review example.

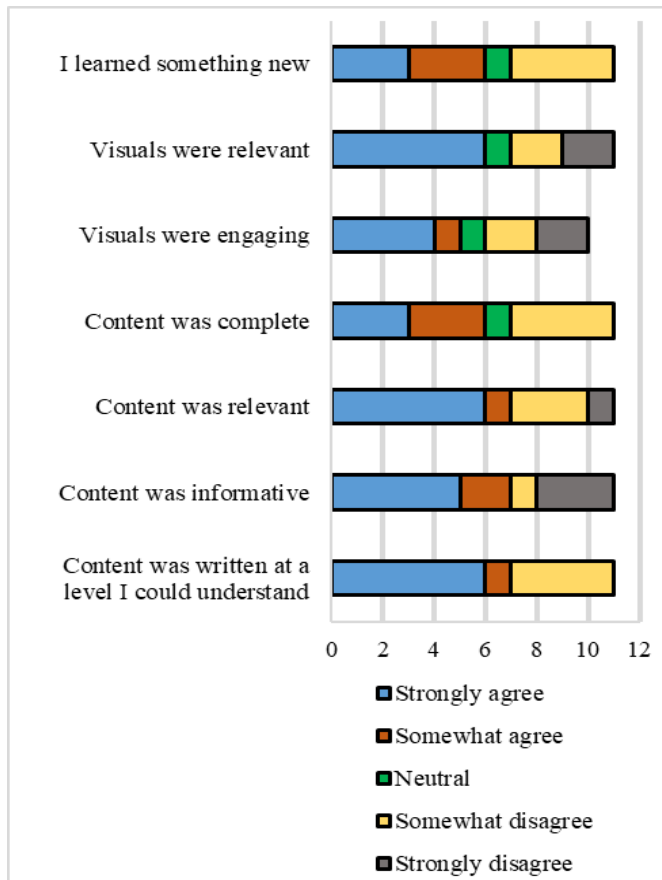


Figure 4. One example of quantitative industry feedback for an educational module from the course IT Fundamentals IT FTasks 39-57: Mastering Digital Technology Basics

Finalized modules were disseminated across Virginia. Data were collected from six other school districts: Martinsville City Public Schools, Montgomery School Division, York County School Division, Charlotte County Public Schools, Roanoke County Public Schools, and Henry County Public Schools for IT Fundamentals. Sixty percent of respondents were actively teaching information technology fundamentals, 40% were not. They like to teach that course, because they like learning and teaching about computers, they feel that students can benefit from this course, that it is very relevant, and that it has a variety of content areas. The biggest challenges that the teachers saw when teaching IT fundamentals were that it had limited hands-on projects, programming issues, and, since it was an elective course, students would not always sign up.

They also reported challenges finding materials for their lessons. When asked to identify the cause of problems teaching an IT fundamentals course, they said that technology changes very fast, budgets were limited, and that they had very little knowledge on how to program. They agreed that up-to-date course materials, hands-on equipment would help them teach this course. They also noted that they would need equipment for simulations and network access. They further noticed that they were spending a great deal of time developing lesson plans. All of the teachers who participated in this study noted that the content was written at a level that they could understand and that the content was informative. Sixty percent somewhat agreed and 30% strongly agreed that the content was relevant, visuals were engaging and relevant, and that they learned something new. The only neutral comment was that the “content was complete.” There were no comments in the “somewhat disagree” and “strongly disagree” categories. Some of the teachers noted that it was hard for them to answer some questions until they had a chance to teach the material, since this course was new for most of them.

The following school districts responded to a survey related to the Cybersecurity Fundamentals modules: Chesterfield County, Roanoke City Public Schools, Rockbridge County Schools, Fredericksburg City Schools, Loudoun County Public Schools, Essex County Public Schools, Charlotte County Public Schools, Cumberland County, Wythe County Public Schools, Newport News Public School, Norfolk Public Schools, Fairfax County Public Schools, and York County Public Schools. Seventy-three percent of the teachers who responded to this survey were already teaching a Cybersecurity Fundamentals course at their school in Virginia. Only one teacher outside of Virginia reported teaching this course, while five others said that they were not yet teaching the course. They noted that they like teaching this course, because it helped them build experience with computer technology and that students could use their knowledge about internet safety even if they did not choose to go into the cybersecurity field. Another teacher noted that the course was a broad mix of topics with many different aspects—it had elements of history, computing, politics, psychology, etc.

Other teachers reported that they did not enjoy teaching this course, since they had not received any training and that there was no available curriculum. They also mentioned difficulties related to transferring all courses to the virtual mode, due to the COVID-19 pandemic. Other teachers noted that it was a current topic and that it should be emphasized in the school system, since there were great opportunities in this field. Some noted that they loved the opportunity to prepare their Title 1 students for the careers out of high school, since the students could obtain certifications that could enable them to work as helpdesk technicians. Some others noted that the class was interesting and challenging. They noted that students loved the classes and enjoyed learning about different threats and that they better under-

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stand the need for cyber professionals. The class topics assisted students in gaining tools needed to appreciate and understand existing cybersecurity threats and to learn how to mitigate them. It was also reported that the students enjoyed learning about the implications of cybersecurity in their daily lives and liked the hands-on activities related to the course. Finally, one teacher noted that they liked the relevance of the content and hoped to inspire students to pursue cybersecurity as a career.

Teachers noted that the biggest challenges or barriers when teaching a cybersecurity fundamentals course were: learning how to do things that they have never done before; keeping student interest going forward throughout the school year; the subject required a lot of critical thinking; and, most Freshmen want to be led through things rather than figuring them out for themselves. Other problems were related to the lack of teacher training and clarity of expectations. They noted that it was difficult to ascertain the level of depth to which they should be addressing the materials from a list of objectives. They noted that it would have been nice to have teacher resource materials and that teachers needed more than just a scenario, they needed answers, outcomes, and expectations. Others agreed that they did not have access to existing curricula for cybersecurity and that they needed more knowledge and more training to gain confidence in the topics.

Teachers also identified challenges in finding and using exercises in a virtual simulated environment, where students could really practice the command-line interfaces and methods used in navigating, configuring, and securing network systems. Teachers suggested that it would be good to develop a logical scope and sequence for the course that uses a building-block, scaffolding approach. They also emphasized that finding and/or creating practical, engaging, real-world labs, activities, and assignments would help them to develop a better teaching and learning environment. They noted that it was hard to browse through the large volume of resources that were available for finding materials that aligned with their vision of what should be taught and how it should be taught within the constraints of the course competencies.

Teachers agreed that the main cause of problems while teaching this course was a lack of available resources. Another problem was that this was a hard subject that required more work than students were accustomed to doing in an elective class. Moreover, they did not have enough financial support from the school system and they themselves did not have such courses while in college. They noted that they needed technology, firewalls, and protocols in place for this class. They also identified the problem that a lot of the cybersecurity resources were very text heavy and did not include any hands-on activities. Others noted that their local computers were locked down so that students could not access operational system configuration or networking features.

When asked to propose a solution that could help them to teach a cybersecurity fundamentals course, teachers suggested that training was the most important thing along with a complete set of curriculum materials. They suggested that the students should be incentivized to get a certification. They noted that even though they did receive invites for some workshops and training, it was hard to find time to attend all required professional development workshops. Some noted that students needed real computers not Chromebooks. They think that they should also apply for grants and donations and keeping machines off the network. They suggested that cyber careers should be mentioned in lower grades and the cyber jobs should be promoted. Teachers agreed that having these slides available in the central repository was a good start to make teaching this class easier. They noted that teachers should collaborate in the development of a curriculum that could be shared.

All teachers agreed that the content was written at a level that they could understand and that the content was relevant and informative. They agreed that visuals were relevant and that they learned something new. Some teachers noted that the content was not complete, as the topic was very broad. Some noted that it was a good place to start but that it should be improved and include the required depth that could give students an adequate understanding of concepts.

## Hands-on Modules

One of the main challenges with distance learning is getting students engaged and perform hands-on activities that increase their understanding of cybersecurity and related applications. Another significant challenge is the need for hardware, such as computers, networking devices, electronics components, materials, as well as an internet connection needed for some hands-on activities. Moreover, it is always hard to run hands-on cybersecurity activities, due to their complexity and the relative high cost of hardware. Distance learning, and the lack of interaction with instructors and peers, makes it even more difficult. For all of these reasons, the approach considered for the practical side of this current project was to first conduct simple, hand-solved activities and then follow them up with hardware-based, more complex activities, developed to help students understand real-world cybersecurity applications.

The research team developed both types of hands-on activities to be conducted with high school students: Introduction to Cryptography and Ciphers was a first step towards cybersecurity with pencil-and-paper type activities; Internet-of-Things (IoT) with Arduino was a hardware-based activity. Students enjoyed both types of activities, but they found the hardware-based ones more difficult, due to their own lack of background and experience with hardware and the IoT concept. The limited time to deliver the activities made it harder for students to grasp concepts from scratch and be able to work on applications other than at the basic level. It is also important to note that, while most

students were using tablets, smartphones, other electronic devices, and in smaller amounts personal computers, they were very intimidated by learning programming and writing their own code. It was for such cyber-related activities to develop student interest in programming and help them make the transition from simple users of software products to actual developers of them.

## Dissemination

The presentations were released to Cybersecurity Fundamentals and IT Fundamentals teachers for classroom use and evaluation to Norfolk Public Schools CTE teachers on August 26, 2020. The need for any supplemental teaching materials was so high that the modules were distributed to teachers even before they were finalized. They were distributed to three high schools that offered these two classes and they will be distributed to all five high schools in the Norfolk Public School system in the 2021-22 academic school year. They were reviewed by the CTE teachers and industry cybersecurity practitioners in the fall of 2020. The research team also met with industry representatives and invited them to form an industrial advisory board for the project and to provide feedback for module improvements. Teachers had a professional development workshop in August of 2020. Ninety percent of the teachers strongly agreed that availability of these modules was empowering teachers to teach cyber courses. One teacher noted that they could use the knowledge and skills gained during this professional development activity to impact student learning.

## Conclusions

One of the main challenges with distance learning is to engage students in active hands-on activities that increase their understanding of cybersecurity and related applications. The other challenge is the need for hardware, such as computers, networking devices, electronics components, materials, etc., in some hands-on activities. It is required to build a virtual learning system with online education and tools, to be able to create a more resilient and educated society for the next generations. Otherwise, the current crisis may cause a worldwide, large-scale issue. Virtual learning environments have been widely used to access information and communication technologies and broadband internet technologies for many years in higher education. It is also becoming more common in high schools, due to COVID-19 and related regulations in recent years. It is expected that virtual learning will be used significantly in all levels of education in the future. However, in order for this to work, resources are needed, such as broadband internet technologies, computers, and environments that support virtual learning through online education and tools. Students should have access to those resources in order to be able to continue virtual learning through the internet or television. In addition, teachers should adapt to new pedagogical concepts and educational modules to teach remotely.

In this paper, the authors presented one initiative to help CTE teachers to quickly adapt to the needs of the new online courses, which is not yet reflected as part of the undergraduate training in the programs that prepare future CTE teachers in this emerging area of cybersecurity. By this method, university faculty can assist high school teachers in teaching the relevant content verified by the incumbent workforce. Students can also be exposed to engineering and engineering technology careers, and, in the long run, educators can create and sustain stronger educational pathways to STEM degrees.

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## Appendix

Task competencies for course # 6670: Information Technology (IT) Fundamentals. These tasks were developed by the Virginia Department of Education's CTE Resource Center (Virginia Department of Education, 2019a). They are provided here just to explain which modules were developed.

### Mastering Digital Technology Basics

39. Investigate the history and emerging advances of digital technology
40. Describe the effect of digital technology on business and society.
41. Describe software associated with information systems.
42. Explore binary concepts and their operations in the digital technology world.
43. Describe the evolution of the Internet and how it works.
44. Investigate emerging technologies as they relate to the future of the Internet.
45. Investigate trends in digital technology.
46. Examine social, ethical, and legal issues associated with digital technology.
47. Debate an ethical issue related to using computer and Internet technology.

### Using Digital Applications

48. Create documents related to real-world business situations.
49. Create a relational database for a real-world business situation.



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50. Create spreadsheets for a real-world business situation.
  51. Create presentations related to a real-world business situation.

#### Investigating Computer Fundamentals

52. Identify the parts of a computer system and the relationships among its components.
53. Describe characteristics and functions of CPUs.
54. Explain the functions and characteristics of system expansion devices.
55. Demonstrate the use of connectivity devices and peripheral equipment.
56. Perform basic operations in an operating system environment.
57. Manage various file types.
58. Describe the computer start-up sequence.
59. Compare operating systems.
60. Investigate needs affecting system purchases and upgrade decisions.
61. Investigate the building stages of a computer.

#### Maintaining, Upgrading, and Troubleshooting Computers

62. Describe the importance of system maintenance and preventive measures.
63. Install hardware in a computer system.
64. Install software programs.
65. Explain the purpose of anti-X software.
66. Identify problems associated with computer hardware, operating systems, and application software.
67. Describe risk-mitigation techniques.
68. Identify security risks inherent to computer hardware and software.
69. Describe security best practices for businesses.
70. Describe the importance of data backup media and strategies.
71. Back up files.
72. Evaluate remote connection troubleshooting.

#### Exploring Network Fundamentals

73. Investigate networks and their evolution.
74. Explain networking concepts and different network structures.
75. Compare peer-to-peer and client-server networks.
76. Describe the differences between analog and digital technologies.

#### Exploring Internet Fundamentals

77. Identify the necessary elements that are required to connect to the Internet.
78. Describe the concept of IP addresses and the Domain Name System (DNS).
79. Explain the delivery methods of ISPs.
80. Compare the types and features of various web browsers.
81. Explain file transfer mechanisms.
82. Exhibit principles of digital citizenship.

83. Identify criteria for conducting searches on the Internet.
84. Assess the effect and value of available firewalls and intrusion detection systems (IDS).

#### Exploring Programming

85. Explain the purpose and functions of computer programming.
86. Identify the types of programming languages.
87. Explain the steps in a program life cycle.
88. Design a simple program for a specific application.
89. Create a simple computer program.
90. Execute a simple program.
91. Document a simple program.

#### Exploring Web Page Design

92. Investigate design elements of professionally developed websites.
93. Analyze the navigation of a website for ease of use.
94. Create a website.
95. Investigate publishing a website.

#### Exploring Graphics and Interactive Media

96. Identify hardware required for multimedia and entertainment presentations.
97. Identify software programs associated with graphics and interactive media.
98. Explore the components of multimedia design and their applications.
99. Explore digital technology as it relates to game design and development.
100. Create an interactive multimedia presentation.

#### Preparing for Industry Certification

101. Describe the process and requirements for obtaining industry certifications related to the IT Fundamentals course.
102. Identify testing skills/strategies for a certification examination.
103. Demonstrate ability to successfully complete selected practice examinations.
104. Complete an industry certification examination representative of skills learned in this course.
105. Complete self-assessments to help determine career development goals.
106. Investigate careers, educational requirements, and certifications in the IT career pathways.
107. Demonstrate project-management skills.
108. Create manual and online employment-related correspondence.
109. Create an electronic and/or hard-copy portfolio.

Task competencies for course # 6302: Cybersecurity Fundamentals. These tasks were developed by the Virginia Department of Education's CTE Resource Center (Virginia Department of Education, 2019b).

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### Exploring Computer Concepts

39. Describe cybersecurity.
40. Define information assurance.
41. Describe the critical factors of information security.
42. Explain cybersecurity services as they relate to intrusion prevention capabilities that protect systems against unauthorized access, exploitation, and data exfiltration.
43. Define risk.
44. Identify the concepts of cybersecurity risk management.
45. Describe cybersecurity threats to an organization.
46. Explain why organizations need to manage risk.
47. Discuss national or industry standards/regulations that relate to cybersecurity.
48. Describe the cyber-attack surface of various organizations.
49. Analyze risks affecting critical infrastructure.

### Examining Computer Networks as a Foundational Element of Cybersecurity

50. Describe a network.
51. Describe a wired/cabled network.
52. Describe a wireless network.
53. Compare cabled/wired and wireless networks.
54. Compare networking conceptual models.
55. Discuss services, their relationship to the OSI model, and potential vulnerabilities.
56. Differentiate among network types.
57. Examine the concept of the Internet as a network of connected systems.
58. Identify networking protocols.

### Understanding Cyber Threats and Vulnerabilities

59. Describe the difference between a cyber threat and a vulnerability.
60. Describe types of cyber threats.
61. Analyze types of current cyber threats.
62. Identify the perpetrators of different types of malicious hacking.
63. Describe the characteristics of vulnerabilities.
64. Identify the prevention of and protections against cyber threats.
65. Identify the cyber risks associated with bring your own device (BYOD) opportunities on computer networks.

### Exploring Ethics as it Relates to Cybersecurity

66. Differentiate between ethics and laws.
67. Distinguish among types of ethical concerns.
68. Define cyberbullying.
69. Identify actions that constitute cyberbullying.
70. Identify possible warning signs of someone being cyberbullied.
71. Identify laws applicable to cybersecurity.
72. Explain the concept of “personally identifiable information.”

73. Explain how and why personal data is valuable to both an individual and to the organizations (e.g., governments, businesses) that collect it, analyze it, and make decisions based on it.
74. Identify ways to control and protect personal data.
75. Demonstrate net etiquette (netiquette) as it relates to cybersecurity.
76. Analyze the social and legal significance of the ongoing collection of personal digital information.

### Examining Data Security as it Relates to Cybersecurity

77. Distinguish between data, information, and knowledge.
78. Identify the most common ways data is collected.
79. Identify the most common ways data can be stored.
80. Explain the difference between data at rest, data in transit, and data being processed.
81. Identify the most common ways data is used.
82. Discuss how data can be compromised, corrupted, or lost.
83. Explain how businesses and individuals can protect themselves against threats to their data (e.g., firewalls, encryption, disabling, backups, and permissions).

### Securing Operating Systems

84. Define the function of a computer operating system.
85. Identify the components of an operating system.
86. List types of operating systems.
87. Evaluate the potential vulnerabilities, threats, and common exploits to an operating system.
88. Identify best practices for protecting operating systems.
89. Describe the concept of malware and techniques to guard against it.
90. Evaluate critical operating system security parameters.
91. Describe security and auditing logs.
92. Describe the role of a system backup.
93. Define virtualization technology.
94. Identify advantages and disadvantages of using virtual machines.

### Programming as a Component of Cybersecurity

95. Define programming in the context of cybersecurity.
96. Differentiate between computer programming languages.
97. Evaluate common programming flaws that lead to vulnerabilities.
98. Identify best practices in secure coding and design.

### Exploring Cybersecurity Implications for Current and Emerging Technologies

99. Identify ubiquitous computing.
100. Discuss security and privacy implications of ubiquitous computing.

### Exploring Cybersecurity Careers

101. Research career opportunities for cybersecurity professionals.

102. Explore the Career Clusters affected by current and emerging technology.
103. Identify the educational pathways for emerging cybersecurity professionals.
104. Identify career paths and job titles within the cybersecurity/cyber forensics industry and Career Clusters.
105. Research the cyber threats and security measures related to career pathways.

#### Preparing for Industry Certification

106. Identify testing skills/strategies for a certification examination.
107. Describe the process and requirements for obtaining industry certifications related to the Cybersecurity Fundamentals course.
108. Demonstrate the ability to complete selected practice examinations (e.g., practice questions similar to those on certification exams).
109. Successfully complete an industry certification examination representative of skills learned in this course (e.g., Microsoft, IC3, and CompTIA).

## Biographies

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# AUTOMATED DOUBLE-CYLINDER SEQUENCE CONTROL: STRUCTURE AND COMMUNICATION

Yuqiu You, Ohio University; Yang Liu, Ohio University

## Abstract

Hydraulic systems can produce large and smooth torques and high-speed responses with fast motions. Therefore, hydraulic applications have been widely developed in industry (Liu & Tang, 2008). Automation applications of hydraulic systems have combined advantages of hydraulic hardware and electronics to achieve more intuitive, reliable, cost effective, repeatable, and user-friendly control systems. In this case study, the authors developed an automated sequence control of a double-cylinder hydraulic system through a networked communication method. In this paper, the authors introduce the hardware components, system configuration, communication setup, programming, HMI (human-machine interface) development, and performance test of the system. The involvement of undergraduate research projects, the utilization of the system, and the future development are also discussed.

## Introduction

Automated hydraulic systems have become an increasingly superior alternative for many industrial applications, due to the advantages noted above. From this project, the authors present here a case study of an automated, double-cylinder, hydraulic positioning control system, along with the design, structure, hardware configuration, communication, programming, and performance of this system. The system included hydraulic cylinders, proportional valves, hydraulic servo drives, sensors, and a Parker automation controller (PAC) that allowed users to control the cylinder motions through a visualized human-machine interface (HMI) from a PC connected to the system or any smart device on the internet. The system was programmed following IEC61131-3 standards on the hydraulic drives and the PAC controller. The servo drives implemented closed-loop control to the cylinders (Parker Hannifin Corporation, 2007). The cylinders' jogging control, positioning control, and velocity control were realized through a closed-loop control method with feedback from the position sensor. The PAC controller coordinated the monitoring and control of the two servo drives through the EtherCAT communication.

## System Overview

The automated hydraulic position control system consisted of two hydraulic cylinders, two proportional valves, two position sensors, two hydraulic drives, and a PAC controller. Table 1 lists the specifications of these major hardware components. The diagram of Figure 1 illustrates the system layout.

Table 1. List of hardware components.

Name	Component Type	Part Number
PAC320	Automation controller	PAC320-CXX2X-XX
Compax3F	Servo drive	C3F001D2F12I11T30M00
DF Plus	Proportional directional control valve	D1FPE50FB9NB00 19
Parker Series SL	Hydraulic cylinder	01.50 F3LLUS23A 12.000
Parker H-Pak	Hydraulic power supply	H1B2 7T10P0X13909/13
Balluff	Magnetic position sensor	Feedback System 0-10V

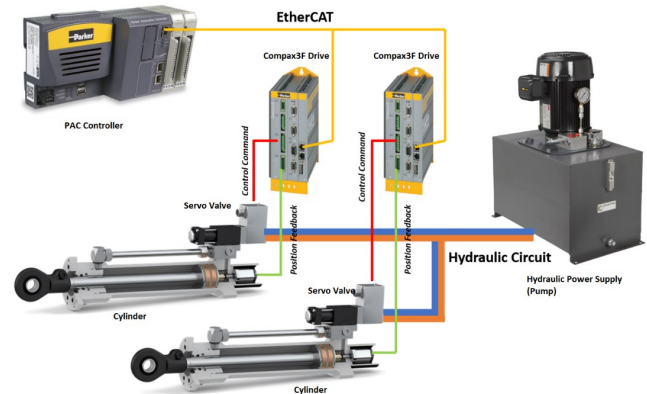


Figure 1. System layout and connection.

Figure 1 also shows how the system incorporates the PAC controller, which is the central controller that monitored and coordinated the two Compax3F drives and provided a visualized HMI for users to interact with the system. The PAC controller was connected to two Compax3F drives using the EtherCAT protocol. Each of the drives directly connected to a hydraulic valve that controlled the flow of the hydraulic fluid in and out of the hydraulic cylinder. The LVDT (linear variable differential transformer) sensors mounted on the cylinders sent positional feedback to the Compax3F drive. Thus, a closed-loop control circuit was effectively implemented on each hydraulic cylinder for position control. Compax3F servo drives control position, velocity, force/pressure of hydraulic cylinders through servo valves. These drives can be programmed based on IEC 61131. IEC 61131 is an international, electro-technical commission standard for controllers (Liu & Peng, 2015).

In this study, Compax3F drives were programmed by CODESYS, which is an IEC 61131 standard software development platform. The servo valves used in this project were DF Plus valves. The valves would drive the cylinders based on input DC signals ranging from -10v to +10v. The position sensor mounted at each cylinder generated a feedback signal proportional to the positional change of the cylinder. The signal was then sent to the Compax3F servo drive to determine the control variables of the cylinders. The hydraulic circuit was another critical component of the system (see again Figure 1). The hydraulic hoses connected the hydraulic power supply (the pump) to the two servo valves that were mounted directly on the two cylinders separately. This circuit provided pressurized fluid to the valves and cylinders and collected return fluid to be sent back to the pump. Figure 2 shows the completed system.

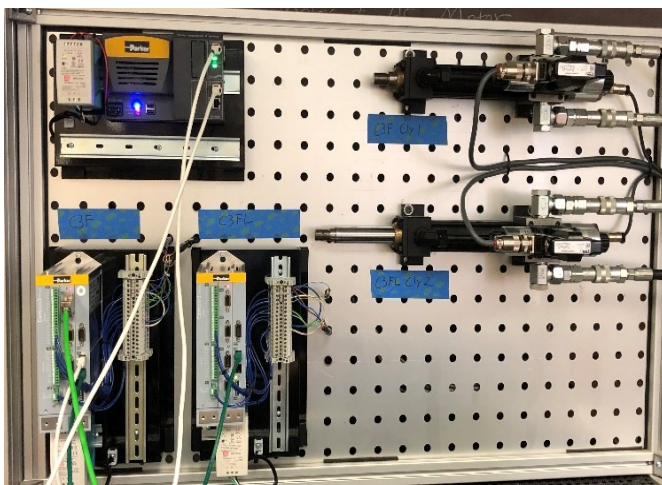


Figure 2. The completed, automated EH system.

## Hardware Configuration and System Communication

The Parker automation controller (PAC) and the two Compax3F drives were the major control devices for motion control in this system. The PAC served as the master control of the system. It handled advanced logic and signal handling, and coordinated multi-axis motion control. It also coordinated the motion controls of the two hydraulic cylinders in the system through the EtherCAT, the synchronized communication fieldbus. The controller was connected to the two Compax3F servo drives, using a daisy chain of EtherCAT cables (yellow lines). The purpose of the PAC configuration was to ensure that the master controller recognized the two Compax3F drives correctly and enabled communications. Figure 3 shows their device configurations and communication setup. The Parker automation manager was the software used for PAC configuration. In the manager, two Compax3F drives were added and specified for the PAC controller. Figure 4 shows the PAC controller and the two Compax3F drives displayed in the Devices Window of the manager.

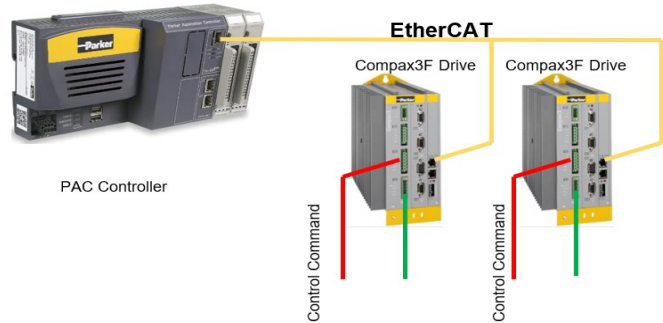


Figure 3. EtherCAT connection.

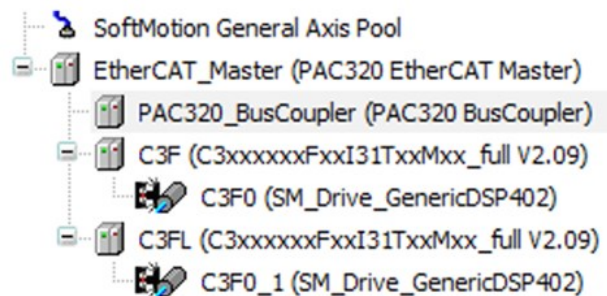


Figure 4. The Devices Window of the configured PAC system.

Compax3F is a programmable hydraulics drive that connects to the valves and implement the motion controls directly. It also interfaces with various input and output devices and implements control functions. Table 2 shows that the drive has modules that can connect to six analog input devices, four analog output devices, and twelve digital input/output signals.

Table 2. The list of drive modules.

X1	Analog Inputs
X2	Analog Outputs
X3	24 VDC power supply
X10	RS232/RS485
X11	2 Feedback T type
X12	Inputs/Outputs
X13	1 Feedback T type

Figure 5 shows how the Compax3F servo drives can be configured using Parker Servo Manager software. The configuration includes the setups of all connected devices and all parameters of the control profile. The major configuration setups are:

1. Axis selection and configuration
2. Sensor configuration
3. Valve configuration
4. Machine zero/homing mode setup
5. Travel limit setting
6. IEC61131-3 variable list for programming

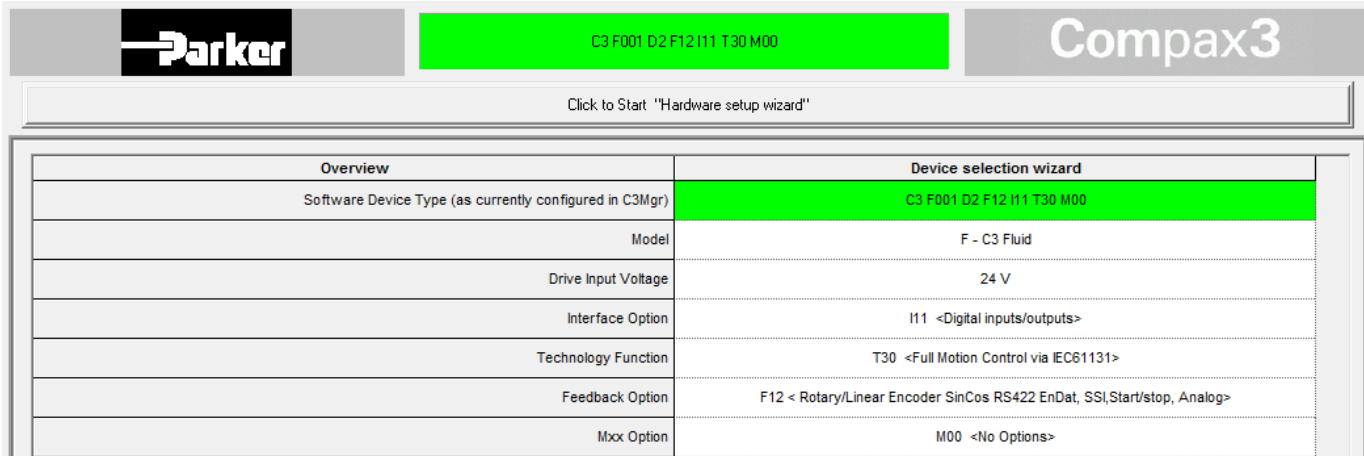


Figure 5. Compax3F drive configuration window.

The hardware configuration of Compax3F servo drives were saved and downloaded to the drives. Correct configurations allowed the drives to recognize the type and parameter settings of all connected devices. Thus, the communication channels with the PAC controller and the hydraulic valves could be established correctly.

## System Programming

The PAC controller and the two Compax3F servo drives were programmed in CODESYS, as noted previously. In CODESYS, control programs can be created with various formats, including Instruction List (IL), Structured Text (ST), Sequential Function Chart (SFC), Function Block Diagram (FBD), the Continuous Function Chart (CFC), and Ladder Diagram (LD) (Fundamentals of Motion Control, 2014; Hanssen, 2017). The programs used in this project were programmed in continuous function charts. In this system, a standard hydraulic servo control program and a PAC program were created in a CODESYS environment. The standard hydraulic servo control program was designed to meet most control requirements for the two Compax3F servo drives. Figure 6 and Table 3 show the state diagram and the functions for the program, respectively.

The completed programs in CFC format were then linked to the Compax3F configuration file in the Parker servo manager environment for both Compax3F servo drives. This combined project configuration and program file was then downloaded to the Compax3F drives to implement control functionality. At the PAC controller, the hydraulic servo input/output signals needed to be mapped to PAC variables through the EtherCAT so that the PAC controller could communicate with the hydraulic servo drives correctly for motion controls. Data mapping was completed by setting up the Expert Process Data tag with input/output assigned with corresponding servo variable addresses and mapping these data to local/global PAC variables (Li & Xing, 2017). Figure 7 shows an example of completed data mapping.

A master program was designed and implemented in the PAC controller. The purpose of the master program was to coordinate the motions of the two cylinders and monitor their status. The major functions implemented in this program included jogging and positioning and three automated sequence-control motions. The preprogrammed sequences could realize motion control, as described below. Table 4 demonstrates the design functions of the master program.

- Sequence 1: cylinder 1 goes forward, while cylinder 2 goes backward; they then alternate.
- Sequence 2: forward positioning one after another
- Sequence 3: cylinder 2 starts positioning after cylinder 1 reaches a specific position.

## System HMI Interface

The HMI was developed by using the visualization function of the Parker automation manager software on the PAC controller. The purpose of this HMI was to provide an interface for users to monitor and interact with the automated double-cylinder sequence control system (Guo, Ye & Wu, 2019). The HMI could be accessed locally through a PC connected to the PAC controller. The HMI could also be accessed remotely through the internet by using the IP address assigned to the Ethernet module of the PAC controller. Figure 8 shows the HMI. The HMI provided three buttons for system control—Power, Reset, and Emergency Stop. These three buttons were used to turn the system on, reset the entered parameters, and stop the motions in emergent situations, respectively. There were two control panels, one for each cylinder on the HMI. Each panel controlled and monitored each cylinder by using the following buttons and indicators.

- Enabled, Error, and Motion indicators to let the user know the status of each cylinder.
- Jog Forward and Backward buttons to manually position each cylinder.

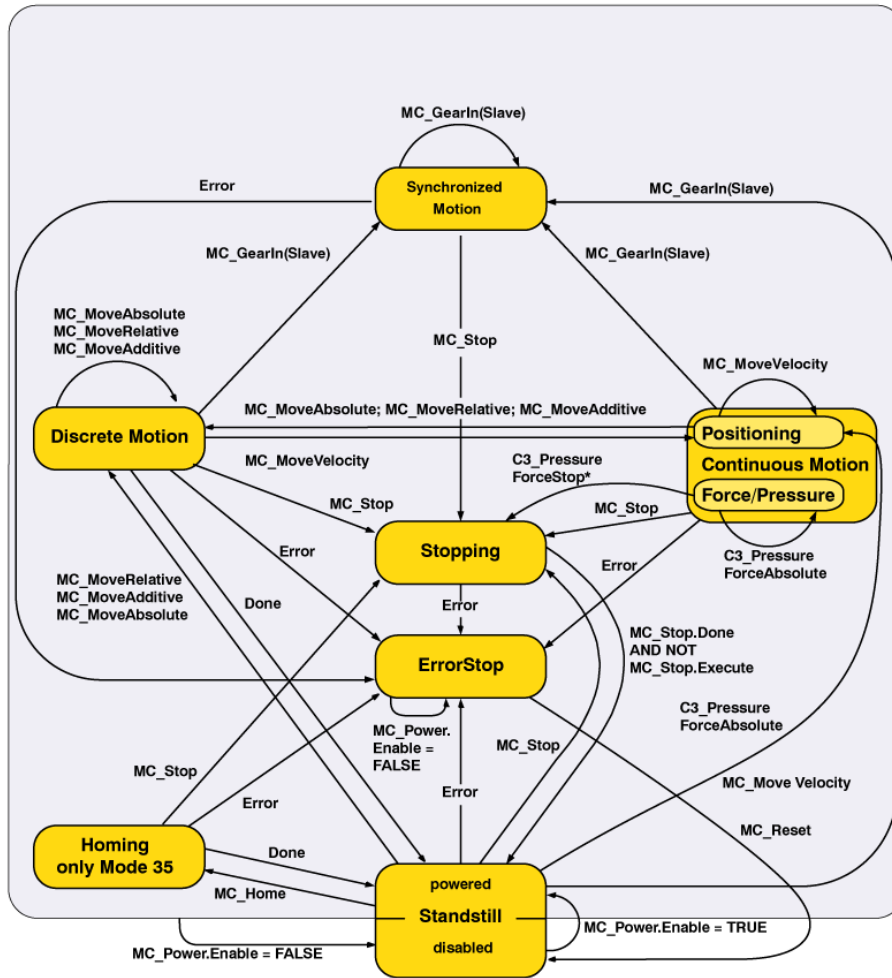


Figure 6. The state diagram of the hydraulic servo control program.

Variable	Mapping	Channel	Address	Type	Unit	Description
		OpMode	%QW0	INT		OpMode
		C3F_ControlWord	%QW 1	INT		C3F_ControlWord
C3F_CMD_Velocity		C3F_CMD_Velocity	%QD 1	DINT		C3F_CMD_Velocity
C3F_CMD_Position		C3F_CMD_Position	%QD 2	DINT		C3F_CMD_Position
		OpMode Display	%IW0	INT		OpMode Display
		C3F_StatusWord	%IW 1	INT		C3F_StatusWord
C3F_STATUS_ActualPosition		C3F_STATUS_ActualPosition	%ID 1	DINT		C3F_STATUS_ActualPosition
C3F_STATUS_ActualVelocity		C3F_STATUS_ActualVelocity	%ID 2	DINT		C3F_STATUS_ActualVelocity

Figure 7. Data mapping.



Table 3. The designed functions of the hydraulic servo control program.

Function Name	Control Function	Inputs	Outputs
Reset	MC_Reset	Axis(int): axis ID Execute(bool): C3Array.Col03_Row01.0	Done(bool):
Power On	MC_Power	Axis(int): axis ID Enable(bool): C3Array.Col03_Row01.1	Status(bool): C3Array.Col03_Row02.0 Error(bool):
Stop	MC_Stop	Axis(int): axis ID Execute(bool): C3Array.Col03_Row01.2 deceleration (Dint): 200 jerk (Dint): 2000	Done(bool): Error(bool):
Status Feedback	MC_ReadStatus	Enable(bool): True Axis(int): axis ID	Done Error ErrorStop(bool): C3Array.Col03_Row02.1 Stopping Standstill DiscreteMotion: C3Array.Col03_Row02.2 ContinuousMotion: C3Array.Col03_Row02.2 Homing SynchronizeMotion: C3Array.Col03_Row02.2
Positioning	MC_MoveAbsolute	Axis(int): axis ID Execute(bool): C3Array.Col03_Row01.5 CMD Position(real): C3Array.Col06_Row02 CMD Velocity(real): C3Array.Col06_Row01 CMD Acceleration (Dint): 100 CMD Deceleration (Dint): 100 CMD Jerk (Dint): 1000 CMD JerkDecel(Dint): 1000	Done(bool): C3Array.Col03_Row02.3 Aborted(bool): Error(bool): Actual Position (Dint[C4_3]): 0x2104 Actual Velocity (Dint[C4_3]): 0x606C
Velocity Control	MC_MoveVelocity	Axis(int): axis ID Execute(bool): C3Array.Col03_Row01.6 CMD Velocity(real): C3Array.Col06_Row01 CMD Acceleration (Dint): 100 CMD Direction(int) (1: positive; 3: negative): C3Array.Col05_Row01	In Velocity(bool): C3Array.Col03_Row02.4 Aborted(bool): Error(bool): Actual Position(Dint[C4_3]): 0x2104 Actual Velocity(Dint[C4_3]): 0x606C
Jog	C3_Jog	Axis(int): axis ID JogForward(bool): C3Array.Col03_Row01.3 JogBackward(bool): C3Array.Col03_Row01.4 CMD Velocity(real): C3Array.Col06_Row01 CMD Acceleration (Dint): 100 CMD Deceleration (Dint): 100 CMD Jerk (Dint): 1000	Busy(bool): Error(bool): Actual Position(Dint[C4-3]): 0x2104 Actual Velocity(Dint[C4_3]): 0x606C

- Home button to fully retract the cylinder to its preset home position.
- Actual Position and Velocity outputs to display the real-time values of each cylinder.
- Input boxes for users to manually set a position or velocity command.
- Execute button to confirm and execute the command.

The HMI also provided three buttons to enable three pre-programmed sequence motions of the two cylinders that were described previously. These sequenced motions could be changed and updated anytime when needed in the CODESYS program on the PAC controller.

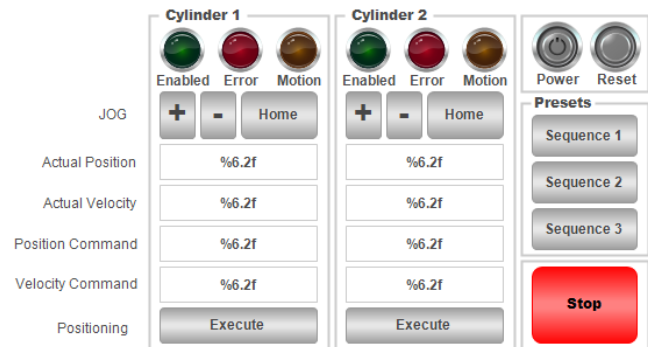


Figure 8. The system HMI.

Table 4. The designed functions of the PAC master program.

Function Name	Inputs	Outputs
C3F_Jog	X+(BOOL): GVL.PB_C3F_JogFWD X-(BOOL): GVL.PB_C3F_JogREV X_Home(BOOL): GVL.PB_C3F_Home X_CMD_Velocity(DINT): GVL.C3F_CMD_JogVelocity	X_Enabled(BOOL): GVL.IND_C3F_Enabled X_Error(BOOL): GVL.IND_C3F_Faulted X_In Motion(BOOL): GVL.IND_C3F_InMotion X_Position(DINT): C3F_STATUS_ActualPosition X_Velocity(DINT): C3F_STATUS_ActVelocity
C3FL_Jog	Y+(BOOL): GVL.PB_C3FL_JogFWD Y-(BOOL): GVL.PB_C3FL_JogREV Y_Home(BOOL): GVL.PB_C3FL_Home Y_CMD_Velocity(DINT): GVL.C3FL_CMDL_JogVelocity	Y_Enabled(BOOL): GVL.IND_C3FL_Enabled Y_Error(BOOL): GVL.IND_C3FL_Faulted Y_In Motion(BOOL): GVL.IND_C3FL_InMotion Y_Position(DINT): C3FL_STATUS_ActualPosition Y_Velocity(DINT): C3FL_STATUS_ActVelocity
C3F_Positioning	X_Execute(BOOL): GVL.PB_C3F_Execute X_CMD_Position(DINT): GVL.C3F_CMD_Position X_CMD_Velocity(DINT): GVL.C3F_CMD_JogVelocity	X_Enabled(BOOL): GVL.IND_C3F_Enabled X_Error(BOOL): GVL.IND_C3F_Faulted X_In Motion(BOOL): GVL.IND_C3F_InMotion X_Done(BOOL): X_Position(DINT): C3F_STATUS_ActualPosition X_Velocity(DINT): C3F_STATUS_ActVelocity
C3FL_Positioning	Y_Execute(BOOL): GVL.PB_C3FL_Execute Y_CMD_Position(DINT): GVL.C3FL_CMDL_Position Y_CMD_Velocity(DINT): GVL.C3FL_CMDL_JogVelocity	Y_Enabled(BOOL): GVL.IND_C3FL_Enabled Y_Error(BOOL): GVL.IND_C3FL_Faulted Y_In Motion(BOOL): GVL.IND_C3FL_InMotion Y_Done(BOOL): Y_Position(DINT): C3FL_STATUS_ActualPosition Y_Velocity(DINT): C3FL_STATUS_ActVelocity
Sequence	Stop(BOOL): GVL.PB_Stop Sequence1(BOOL): GVL.PB_SEQ_Num1 Sequence2(BOOL): GVL.PB_SEQ_Num2 Sequence3(BOOL): GVL.PB_SEQ_Num3	X_Enabled(BOOL): GVL.IND_C3F_Enabled X_Error(BOOL): GVL.IND_C3F_Faulted X_In Motion(BOOL): GVL.IND_C3F_InMotion X_Position(DINT): C3F_STATUS_ActualPosition X_Velocity(DINT): C3F_STATUS_ActVelocity Y_Enabled(BOOL): GVL.IND_C3FL_Enabled Y_Error(BOOL): GVL.IND_C3FL_Faulted Y_In Motion(BOOL): GVL.IND_C3FL_InMotion Y_Position(DINT): C3FL_STATUS_ActualPosition Y_Velocity(DINT): C3FL_STATUS_ActVelocity

## Conclusions and Future Work

In this paper, the authors introduced the development of an automated, dual-cylinder sequence control system with its structure, hardware configuration, communication, and programming. The purpose of this project was to provide a real-world, electrohydraulic system for students in an engineering technology program. Another purpose was to provide a remote laboratory for students to gain hands-on experiences, when an in-person laboratory was not available, such as during the COVID-19 pandemic. Remote access to the physical system with system operations and monitoring was later available to the HMI interface on the PAC controller. However, future work is needed in order to realize more advanced functions for remote laboratories, such as remote HMI configurations, remote programming, and login security and safety management.

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# INTEGRATING REAL-WORLD EXPERIENCE INTO A SENIOR CAPSTONE DESIGN

Maged Mikhail, Purdue University Northwest; Dominic Guevara, Purdue University Northwest

## Abstract

Figure 1 shows the MasterCap, four-bottle automatic rotary capping machine that Purdue University Northwest owns, which was acquired in hopes of training engineering and engineering technology students on real-world applications of programming, troubleshooting, and maintaining industrial equipment. The machine, while fully assembled, is missing some key mechanical components, and no connection to the programmable logic controller (PLC) has been made. A team of students was put in charge of troubleshooting and repairing the machine as a senior capstone project. The machine required two conveyors to be installed in order to move bottles and caps to the capping area. The machine's electrical connections had to be checked to ensure that it matched what was detailed on the electrical schematic. Lastly, in order to achieve a functional machine, it was necessary to retrieve the program off of the PLC and reprogram any necessary portions, as applicable. The aim of this study was to demonstrate the real task in mechatronics when the student team applied practical knowledge under the guidance of an instructor.

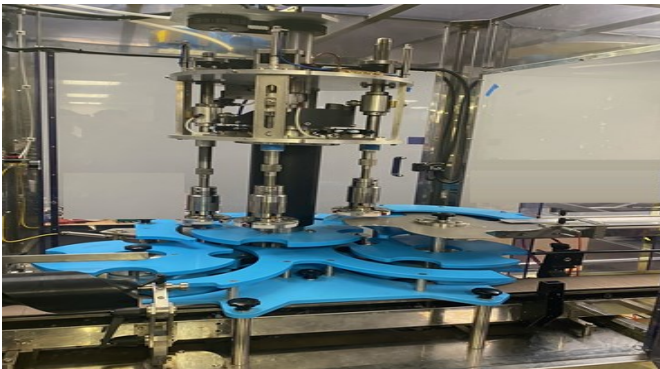


Figure 1. Capping machine.

## Introduction

The bottle conveyor belt was identified as a straight running, carbon steel belt. This was never ordered, because PNW professor Rick Rickerson asked the team to find a replacement drive with a plastic belt as a cheaper option. The replacement drive and conveyor for the bottle conveyor system was identified. Shaft and keyway verification were required before it was known for certain whether or not it would work properly. The machine utilized pneumatic actuators to grip and release the bottle caps, and it was adjusted to actuate where the team believed would be the proper places to grip and release the caps.

When the team left, the machine was running in the proper direction to cap the bottles. If the cap conveyor were redone and the correct bottle conveyor were installed, the team believed that the machine would be able to cap the correct bottles. However, due to unforeseen circumstances revolving around the global pandemic, the university closed its campus, thereby preventing the team from progressing further.

## Project Goals

When there are plans to follow, this will increase the ability of the team members to focus on their goals. Since running this machine was the main goal of this project, the team members decided to come up with these additional goals.

- Have a functional PLC program and to install the missing conveyors so that the machine is operable and correctly caps bottles fed into it.
- Require that all missing parts be found or ordered in order to have the chance for testing the machine and determine what else needs to be done.
- Require that team members gather a list of research references in order to aid in completing the project.
- At the end of this semester, the team should be able to have every part fixed and assembled.

## Project Specifications

The project specifications were accurately focused on by the team members to make this project succeed. Since this machine was already mechanically assembled correctly, the focus was directed to identifying missing components and repairing any electrical and logic problems. Once the missing components were identified, a budget was presented to the students' capstone advisors so that the missing components could be acquired. Since this would be the first time the machine would be used once repaired, the team aimed for successfully capping 20 bottles to prove proof of concept.

- The machine must cap at minimum 20 bottles.
- All equipment, electrical, logic, and mechanical, must be inspected and repaired, if necessary.
- The machine must be safe to operate with proper guarding and signage installed.

## Methodology

This project required a complete program of the machine's PLC logic and a functioning emergency stop electrical system. Functions such as the emergency stop are



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crucial not only for safe operation but to meet safety standards as well. In his book, Bolton (2015) gives examples of both unsafe and safe emergency stop system setups. He explained that it is a safer system setup if the emergency stop relay is set up independently of the PLC so that it stops power to the motor and triggers a safe shutdown program in the PLC. In another book (Ridley, 2003), the author describes what subroutines are and how they function in PLC programming. That author also provided pictures of simple subroutine rungs as an example of an application. The machine's PLC was programmable via the program RSLogix 500, which is different from the Studio 5000 that the team was trained on.

Thankfully, Rockwell Automation has a PDF version of the training manual associated with RSLogix 500. This has been an incredibly useful resource to the team as it contains all of the information needed to get the PLC system ready to be programmed. Rockwell Automation (2018) includes a section on automatically configuring the I/Os, which will be extremely useful in expediting the remapping process. The machine also contained two conveyors, one for the bottles and the other for the bottle caps. Garrity (2019) described basic gravity and powered conveyors, giving examples on what bearing to choose for the environment being worked in, and described load characteristics on conveyors.

## Repair and Troubleshooting

Upon the team's initial inspection of the machine, while fully assembled, the team was told that power had not been established and the original cable was missing. With the help of Professor Maged Mikhail, the team found a 3-phase power cable and wired the leads directly into the machine's main panel box. Once completed, power was restored to the machine's basic components—the PLC's central processing unit (CPU) (SLC 5/04), human machine interface (HMI), and a 24VDC power supply. While power was restored to some of the components, the machine remained inoperable, because the variable speed drives (VSDs) were still unpowered. The VSDs control the operation and speed of the machine's 3-phase motors; there is an independent VSD controlling each motor separately.

When power was restored to the PLC, the team focused on making a connection to the PLC's CPU. Connection to the CPU could be made via an RS232 serial data port located on the CPU module and using RSLinx Classic to configure the connection automatically. The team had initially been given a standard RS232 serial data-to-USB cable; however, the auto configuration was unsuccessful. The team then purchased another standard RS232-to-USB cable, presuming the initial cable was bad, but RSLinx Classic was still unable to generate a configured connection with the new cable. The team contacted Professor Mikhail to ask if he had any possible solutions to the problem. He gave the team the contact information to Rockwell Automation's support line.

Upon contacting support, the team explained the problem and what cables were being used. The support representative explained that the RS-232 modem serial data cable must be of the null type, which the cables used were not. The team then purchased a null modem RS-232-to-USB cable and retried the auto configuration, and this time was successful. Once the connection was configured, the team proceeded to use RSLogix to try and retrieve a program off of the CPU. A program was, in fact, stored within the CPU, and the team successfully extracted a logic program. When inspecting the program, there were 19 subroutines controlling the machine; however, the team noticed that five of the subroutines were blank. The team then made a backup of the original program and deleted the empty subroutines off the backup copy. The extracted program had no labels or comments to help identify what the individual I/Os were and what they controlled. The team then used the electrical schematic, which identifies where each I/O is wired to the PLCs input and output modules in order to correctly label the I/O in the program and make it easier to understand how the program operates.

The next step was to figure out why the VSDs were not being powered. Based on the electrical schematic, the motors each had independent relay systems, all directly tied into the machine's safety relay system (SRS). The team then began to trace back all the wiring in the SRS to ensure it was wired properly so the circuit could be completed. The physical trace back proved that the circuitry was indeed wired properly, yet the connection was still not complete. Next, the team checked for continuity between all the contacts. A closer look at the door switches revealed that a problem lay with the disk feeder door sensor. It should be noted that an alarm on the HMI display indicated that a door was open and that this was an assembly that was not attached to the machine at all, and the sensor, while wired, was not attached to any physical door or latch.

The team then used a wire nut to turn the normally open (NO) contact into a normally closed (NC) contact. After doing so, the open-door alarm disappeared from the HMI, but the SRS remained unpowered. At that point, the team contacted electrical engineer Jared Goodall for help in understanding why the SRS remained unpowered. Jared and the team rechecked the continuity in the SRS, and he helped determine that a problem still existed in the disk feeder door sensor. While the one connection was manually bridged and resolved the door alarm, there was another limit switch sensor that was not closed. The team assumed that because the alarm disappeared the problem in the sensor was solved; however, Jared helped to realize and understand that when the sensor was not actuated, the labeled contacts on the sensor were essentially flipped, NO becomes NC and vice versa. When the team powered the machine on after this was complete, the SRS was completed properly, as the two indicator lights illuminated at that point and the VSDs received power.

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With the machine being fully powered, the team attempted to run the machine by pressing the capper, inch, and conveyor buttons. However, the only motor to activate was the bottle conveyor drive motor. A closer look at the ladder logic revealed that in LAD 4 rung 0000, the machine's air pressure sensor needed to be activated in order to complete the rung and allow further rungs to be completed. The team then built an air supply hose using tubing and fittings provided by the university. The data sheet on the air pressure sensor indicated that it should be activated between 2 and 10 bars or pressure. By adjusting the pressure flow on the air filter regulator lubricator (FRL) system attached to the outside of the machine to three bars, the team noticed air leaks in the system and that the sensor had not actuated, despite being supplied air. The first leak the team found was in the fitting leading out of the FRL to the machine's pneumatic components. The team purchased a new plastic push connect fitting from a local retail store to replace the leaking one that was attached to the FRL.

Once replaced, a new leak became audible at the T fitting, with one direction leading into the air pressure sensor and the other leading directly to the pneumatic system controlling the bottle cap gripping system. The team then purchased a replacement plastic T fitting, plastic adapters, and plastic tubing to replace the fitting itself and the tubing leading from the FRL to the tee fitting; due to the thread size and the limited selection of fitting and adapters available at the store, the team used three adapters to achieve a connection from the T fitting to the pressure sensor. Replaced, another leak appeared leading from the output of the pressure sensor to the machine's less critical pneumatic systems that controlled the cap reject system. There were multiple air lines unattached to any pneumatic subsystems, so the team proceeded to plug them into their corresponding terminals on the manifold. On the machine, the team figured out that red lines indicated a feed and the blue lines indicated what they believed to be a return line. There was a pneumatic manifold located under the capping area, which had multiple leaks as well. At this point, the team decided to route the outgoing air from the FRL directly into the cap gripping system to temporarily bypass the systems that were leaking until they could acquire better fittings to fix the leaks.

After rerouting the pneumatics, the team then altered the original PLC program and forced the air sensor on to complete rung 0000 of LAD 4. Once completed, the team tried to start the machine by pressing the capper, conveyor, and inch buttons, but again only the conveyor motor turned on. Looking again at LAD 4, the team noticed that there was a set of binary files that prevented the main capper motor and the capping spindle from being powered on. On LAD 4 rung 0002, binary file B3:2/12 was initially set to zero, which prevented LAD 4 rungs 0011 and 0012 from completing; 0011 controlling the main capper motor and 0012 controlling the capping spindle drive. Then the team looked through the rest of the existing subroutines and

found that nothing they used would actuate or control the value assigned to B 3: 2/12. The team discovered that the file value was manually changed from 0 to 1; this allowed LAD 4 rungs 0011 and 0012 to be completed with the use of the inch button. The team then downloaded the new program to the PLC. Once downloaded, the team hit the conveyor button and capper button, and both the conveyor drive and the capping spindle motor powered on.

Next, the team held down the inch button and the main capper motor powered on, meaning that all essential motors that operate the capping function were working. However, the team noticed that the machine was running in reverse, against what would be the flow of the bottle conveyor. To fix this, the team identified the 3-phase power leads, leading out from the main motor VSD drive and flipped wires 34 and 36 to reverse the polarity of the motor so that it would be running in the proper orientation. It should be noted that the main motor drive VSD could be reprogrammed; however, flipping the phase was a simpler fix. Next, the team focused on getting both the bottle and the cap conveyor belts ordered. Because the bottle conveyor belt was a specialty drive that needed a specific pitch and belt type, the team got in contact with Alan Coyle of Morrison Container Handling Solutions.

The team sent him a SolidWorks model of the conveyor drive found on the original manufacturer's (Rexnord) website, pictures of the drive, and the following dimensions: number of grooves, groove width, and groove depth. Alan provided the team with the correct pitch of the drive, 1.5 inches, as well as a straight-running belt that would fit the drive, which was the Rexnord 821 series plastic straight running tabletop chain. Upon looking at the recommended belt, the team realized two issues with that series. The smallest width of belt in the series offered was 7.5 inches, and there was a small flange vertically connecting the horizontal hinge links. The machine accepts a maximum belt width of 4.5 inches, which was determined by a plastic piece guarding the chain that it would ride on so as to not have contact with the steel rails itself; the team installed the plastic guarding. The pitch, however, was the important piece of information that the team needed to have verified; then, with the correct pitch, the team identified a replacement belt with the proper width constraints and pitch. This belt was identified as the Rexnord 815 series straight running tabletop belt.

However, instead of being made of plastic, the belt was made of carbon steel. The team found that there used to be a plastic version of this belt; however, according to Rexnord's website, it was a discontinued product, leaving the carbon steel belt as the only option. The team then contacted lab administration with the ordering information to purchase the belt. After talking to the distributor, the lab administration responded saying that the carbon steel belt for the existing drive would cost \$1206.80. He asked if the team could find a replacement drive sprocket and plastic chain that may

ultimately be a cheaper option than the carbon steel belt that fits the existing drive sprocket. The alternatives were identified as the Rexnord 820 series tabletop straight running chain and sprocket. The chain product number is 793699172171, and the sprocket product number is 698210858094. It should be noted that the sprocket was subject to change only due to shaft diameter and keyway size, because the team was unable to verify those dimensions due to lack of access. This sprocket had a shaft diameter of 1 inch. The sprocket series had the same overall outside diameter as the existing drive, 6.032 inches, and the sprocket also had to have 25 teeth to match the groove count on the existing drive.

The team did not have price quotes for the replacement drives, as they required a quote from a distributor such as Motion Industries. Next, the team worked on installing the cap conveyor belt. The belt ordered from McMasterCarr was a white polyurethane flat belt with a width of 4 inches and a total ordered length of 16 feet. The needed belt length was measured by wrapping the belt length around the entire length of the cap conveying system and marking the cut off length with a sharpie. The team then cut the belt by hand using belt snips and used a hammer on style hooks also ordered from McMasterCarr to have a means to connect the two ends. The belt was wrapped around the system and the loop was closed using a small connecting rod. At this point, the team realized the belt ordered was slightly too wide for the drive pulley; however, by hand turning the conveying system, the team realized there was a possibility it may still work, as it was able to complete a full revolution. The team believed the width discrepancies were due to using an old tape measure to measure the width of the drive. The team attempted to force the cap conveyor using the PLC to see if it would rotate via the motor, but it did not. The belt would have to have its width trimmed and reinstalled for proper seating of the belt in the drive pulley. Alternatively, a new belt with a slightly smaller width could have been ordered.

The team had initially planned to use a generic peanut butter jar that fit within the machine's bottle and cap tolerances and which would also provide a small load for the bottle conveyor system to undergo. The peanut butter jar was a Dollar General store brand, Clover Valley, with a net weight of 2.5 lb.; the product number was 00870601. Another bottle had also been selected for use, which could be obtained through the distributor, the Cary Company, that also fit the machine's bottle and cap tolerances and in addition was slightly taller than the initially selected peanut butter jars, which may possibly be a better fit for the machine's height tolerances. The jar's product number was 67W52W, with a diameter of 3.99 inches, a height of 7.75 inches, a neck finish of 100-400, and an overall capacity of 52 ounces. The associated cap's product number was 67W100 with the same neck finish of 100-400, meaning that the two were compatible. At the time, the Cary Company required a minimum order of \$250, with the jars being sold in quantities of 84 at \$1.330/ea. and the caps being sold

at \$0.287/ea. To reach the current order price minimum, 168 count of both the jars and caps needed to be ordered with the total price being \$271.66.

## Project Calculations

The machine needed two conveyor belts to operate properly, one to move the bottles and the other to move the caps. The critical conveyor system was the one moving bottles, as it needed a specialty drive and chain to operate and the motor controlling it had a maximum of 0.47 kW of power available for use. Unfortunately, the manufacturer of the specialty conveyor belt for the bottles did not list any weight specifications for either the carbon steel chain or the plastic chain. Those weights are typically needed to see if the motor is powerful enough to move the expected load and the weight of the belt itself. The calculations provided, though, explain the theoretical power that was needed to move the expected load, the maximum weight for the bottle conveyor chain, and the minimum length requirements for both the bottle and cap conveying systems.

The power for the belt conveyor was determined by Equation 1. The expected load was 20 bottles each with a net weight of 2.5 lbs. per bottle.

$$\text{expected load} = (\text{net weight / bottle}) * (\text{num. of bottles}) = \\ 2.5 \text{ lbs.} * 20 = 50 \text{ lbs} \quad (1)$$

Next, the team needed to find the belt pull of the bottle conveyor system. Belt pull is described as the estimate of the force a belt exerts on a shaft. It is the force applied to a shaft by the two belt spans entering and exiting a pulley. The authors found the following on [www.tribology.com](http://www.tribology.com), which yielded Equation 2.

$$\text{Belt pull} = \text{load} * f_c \quad (2)$$

where,  
 $f_c$  = friction coefficient

The dynamic range for plastic on plastic is 0.2-0.4. The authors chose 0.4 for their calculations. Thus, 50 lbs. \* 0.4 = 20 lbs.

This does not include the weight of the conveyor belt itself, which should be included in the total weight. However, the carbon steel or plastic belt the team found had no listed weight per foot or anything describing estimated weight on the manufacturer's website. In lieu of this, the approximate power, in kilowatts (kW), required to move the calculated expected belt pull was then based on how much power the motor would have left to pull; that number was used to estimate the maximum belt weight. The belt speed was found by multiplying the drive sprocket diameter by pi and the rpm the drive was spinning at. The drive sprocket was found to have a diameter of approximately six inches

and the rpm was found to be 172, which was found using a photo tachometer, as shown in Equation 3:

$$\text{Belt speed} = (\text{drive sprocket diameter in feet}) * \pi * (\text{RPM}) \quad (3)$$

$$\text{Mean } 0.5(\pi) * (172) = 270 \text{ ft} / \text{min}$$

The required power (kW) needed to move the belt pull is the belt pull multiplied by the belt speed. Since the team did the calculations based on imperial units, they first calculated the required power in horsepower (HP), then converted that figure into kW, as those are the units that the motor is rated at, which was found to be a maximum of 0.47 kW, based on the motor's nameplate (see Equations 4-6).

$$\text{Required Power} = \text{belt pull} * \text{belt speed} \quad (4)$$

$$20\text{lbs} * 270\text{ft} / \text{min} = 5400 \text{ (ft} * \text{lbs.)} / \text{min.}$$

Convert the required power to horsepower :

$$1 \text{ HP} = 33000 \text{ (ft} * \text{lbs.)} / \text{min} \quad (5)$$

and  $5400 / 33000 = .1636 \text{ HP}$

Convert to watts from HP |  $W = \text{HP} * 746$

$$0.1636 * 746 = 122.07\text{W} \quad (6)$$

$$122.07\text{W} = 0.12207 \text{ kW}$$

Since the motor was rated for 0.47 kW, the motor was determined to be powerful enough to move the expected load. The first step in finding the maximum bottle conveyor belt weight was to find the remaining power available, in kW, by subtracting the total available power of the power to move the expected load with no belt (see Equation 7).

$$\text{Remaining power (kW)} = \text{Total Power} - \text{Expected Power} \quad (7)$$

$$0.47 \text{ kW} - 0.12207 \text{ kW} = 0.34793 \text{ kW}$$

$$0.34793 \text{ W} * 1000 = 347.93 \text{ W}$$

Next, power was converted to HP by Equation 8:

$$\text{HP} = W / 746, \text{ mean } 347.93 / 746 = 0.4664 \text{ HP} \quad (8)$$

The next step was to find the power in ft\*lb/min, as determined by Equation 9:

$$\text{Power in ft} * \text{lb} / \text{min} = \text{HP} * 33000 \quad (9)$$

$$0.4664 * 33000 = 15391.2 \text{ ft} * \text{lb} / \text{min}$$

Next, the team had to work back the belt pull using the power in ft\*lb/min and the belt speed (see Equation 10).

$$\text{Belt pull} = \text{Power} / \text{Belt speed} \quad (10)$$

$$(15391.2 \text{ ft} * \text{lb} / \text{min}) / (270 \text{ ft} / \text{min}) = 57 \text{ lb.}$$

Lastly, the maximum belt weight could be found by dividing the belt pull by the coefficient of friction, completing the calculation of maximum belt weight through the available power left in the motor (see Equation 11).

$$\text{Belt weight} = \text{BP} / \text{fc} \quad (11)$$

$$57 \text{ lb} / 0.4 = 142.5 \text{ lb.}$$

Based on the calculations, the maximum weight of the bottle conveyor chain considering the expected load was 142.5 pounds.

This section explains the minimum length of chain calculation for the bottle conveying system. Essentially what was needed was the center-to-center distance plus the circumference of the drive sprocket, since the sprocket and roller support shared the same diameter.

- The center-to-center distance was 17' 8"
- Drive gear and roller diameters were both 6". The radius was 3".
- Use the circumference formula (Equation 12) to find the total length for both hemispheres.

$$C = 2\pi(r) = 2 * \pi * (3) = 18.85" \quad (12)$$

$$\text{Total bottle belt length} =$$

$$2 * \text{center to center} + \text{Circumference}$$

$$\text{Total} = 2 * 17'8" + 18.85 = 36'8(27/32)"(\text{min})$$

To find the bottle cap conveyor belt minimum length, the same method as used as with calculating the bottle conveyor distance. It should be noted that for the cap conveying system the drive pulley was slightly larger than the roller pulley, and for simplicity the circumference of the drive pulley was used to calculate the length of both semicircular ends. This yielded a slightly larger result than what the actual minimum length was, though the difference was negligible.

- The center-to-center distance was 7'.
- The drive pulley diameter was 2.5". The radius was 1.25".
- Use the circumference formula (Equation 13) to find the total length for both hemispheres.

$$C = 2\pi(r) = 2 * \pi * (1.25) = 7.85" \quad (13)$$

$$\text{Total length} = 2 * \text{center to center} + C$$

$$\text{Total} = 2 * 7' + 7.85 = 14'7.85"(\text{minimum})$$

## Safety

Safety was the number one concern when completing the project. While on any jobsite, there are safety standards that must be followed when working around moving machinery. The team completed a safety hazard assessment and detailed



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the preventative measures that had to be put into place before operating the machine. The risk level results for each hazard were provided before and after solving them.

## Electrical Shock Hazard

The electrical hazard could be very dangerous with severe consequences for workers in cases of direct electrical contact to the running machine or an improperly insulated conductor. The result of direct contact to an electrical hazard could be electric shock, different types of burns, as well as blast injury (Workplace Safety & Prevention Services, 2021). The risk level of this hazard was 20—catastrophic (frequency of 4 \* severity of 5). This hazard had a risk level of 20, because, when it happens, a person will most likely die. Therefore, the impact of this hazard is dangerous, and it was on the top of the team’s list of considerations. The solution for electrical/shock hazard was organizing all electrical wires and labeling them correctly to avoid any possible shocks. For the unregulated power supply, having a lock/tagout on box number two of the machine would notify all workers of the danger in this area. In this case, the risk level result dropped to 6 (frequency of 2 \* severity of 3), because all wires were placed in the proper areas; thus, there was no electrical threat to the team.

## Snag Hazard

A snag hazard is where an individual can get loose clothing or long hair caught on a part of the machine. This machine had a lot of snag hazards from the sharp edges to the moving parts that could snag clothes, hair, or anything else dangling or hanging off a person’s body. This hazard had a risk level of 16 and was considered a major problem (frequency of 4 \* impact of 4), because it could possibly happen often when people work on this machine with long sleeves or hair not properly tied up. However, the impact of this hazard could be severe, if something gets snagged on a moving part of the machine. The solution for snag hazard was preventing all workers from wearing loose clothing, jewelry, rings, watches, or the like while working on the machine. In this way, the danger of the risk level for this hazard was reduced to 6—low (frequency of 3\* severity of 2).

## Moving Parts/Flying Materials

Running conveyer systems carrying a heavy load with fast speeds and sharp edges are very dangerous. Myriad hazards can be caused by this type of system, including indirect (slipping and falling or parts ejected from the machine) and direct (contact with moving machine parts) bodily injuries (ESS Engineering, 2019). This machine had a lot of moving parts from end to end. This was one of the more serious hazards. Since there were so many moving parts, the team members had to be careful and make sure that the machine was completely off while working on it.

Additionally, flying materials from the machine—such as chips—were capable of causing eye injuries. This hazard had a risk level of 12—serious (frequency of 3 \* impact of 4), because with this machine having so many moving parts, any chance could occur to slip or fall while moving these parts. Also, flying materials could occur while using drills. The solution for moving parts/flying materials was organizing all parts of the machine and removing them from the sidewalk. Placing all equipment in appropriate areas would avoid any slip or fall injuries. Having safety glasses on all the time while working on the machine would prevent eye injuries. In this case, the risk level went down to 6—low (frequency of 2 \* severity of 3), because all needed supports were provided to prevent any similar injuries that could happen from this hazard.

## Pinch Points

“A pinch point is defined as any point where it is possible for a body part to be caught between moving and stationary portions of equipment” (Pinch Point and Hand Injuries, 2019). The main area where pinch points were on this conveyor was the main rotary capping section. This area had multiple moving parts and a stationary bottom piece. The risk level of this hazard was 16 and was considered a major problem (frequency of 4 \* impact of 4), because there were some open areas on the machine, such as the starting location of the bottle conveyor and where the caps conveyor was located. If a person accidentally placed his/her hands on these areas while the machine was running, the person’s hand could be dragged into the machine and cause extensive injury. The solution for pinch points was having do-not-touch signs on these areas when the machine is running. In this case, all workers would be aware of the consequences of this hazard and the risk level would go down to 6—low (frequency of 2 \* severity of 3). In addition, safeguards existed in the machine to prevent people from putting their hands in there. Also, before opening the safeguards to enter the area, the person had to hit the emergency stop button to stop the machine, so this hazard should not happen often, when all guarded equipment is present.

## Conclusions

At the start of the project, the machine was completely unpowered, with no proof of any working motors, I/O, or usable PLC program. Using the electrical schematics of the machine, the team traced back the wires of the SRS and the motors of the machine to ensure it was wired in accordance with the schematic. The team found that it was wired properly; however, because a door sensor was missing its actuator, the SRS was not completing its circuit. Upon manually bridging the connection via wire nuts, the machine’s power was restored. The pneumatic gripping actuator plates were adjusted to where they could pick up and release caps in the proper sequence. The team was unable to move forward with the project, due to the university restricting all

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access for the remainder of the semester after spring recess. The machine was at a point where, if both the bottle and cap conveyors were installed, the machine should run when pressing the inch button. The bottle conveyor had been identified as either the Rexnord 815 series carbon steel straight running chain with a pitch of 1.5 inches to fit the existing drive, or a Rexnord 820 series tabletop straight running chain and associated drive sprocket as a replacement for the existing drive sprocket. Minor adjustments had to be made to the actuating plates controlling the gripping and release of the caps once running. For machine operation, the bottles and caps had to be lined up on the ends of their respective conveyors. The conveyor and capper buttons had to be pressed. The main capper motor drive controlled the rotation of all the star wheels and the timing screws and ensured that they remained in perfect time with each other. The bottles would then be moved by the outfeed star wheel back onto the bottle conveyor where the capping process ended.

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## Biographies

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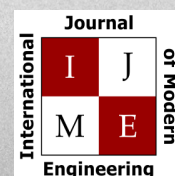
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